
NuFACT 2022

WG2 Summary

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U N I V E R S I D A D
COMPLUTENSE
M A D R I D

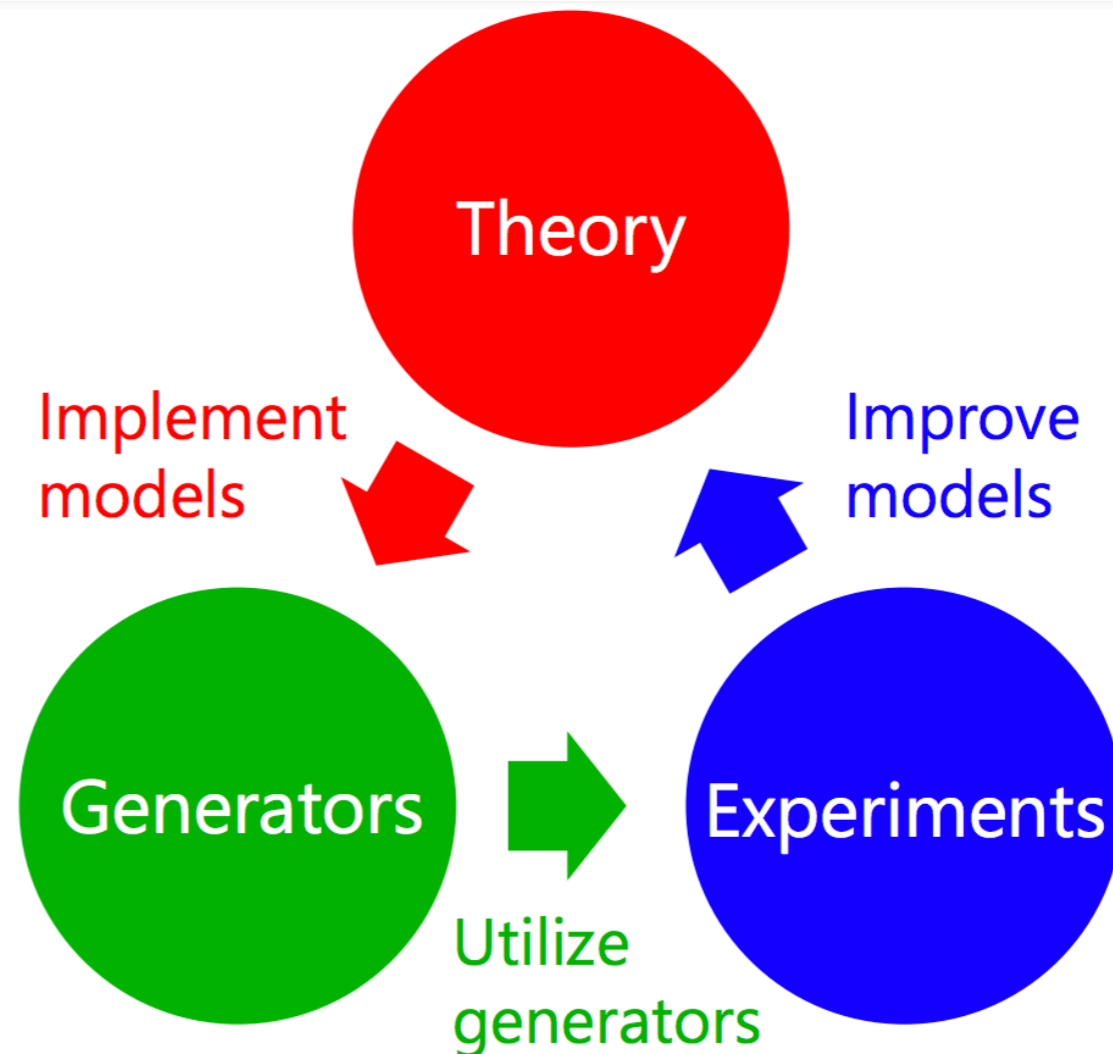
Adi Ashkenazi



TEL AVIV UNIVERSITY

WG2 - Neutrino Interaction

- Experimental efforts
 - 16 talks (12 on cross section measurement, 2 on electron scattering, 4 on flux prediction)
- Theory inputs
 - 5 talks
- Generator developments
 - 2 talks
- Joint session WG1-WG2: Constraining Xsec systematics / Xsec tuning
 - 4 talks
- Joint session WG1-WG2-WG6: Near detector constraints
 - 5 talks



Theory Input

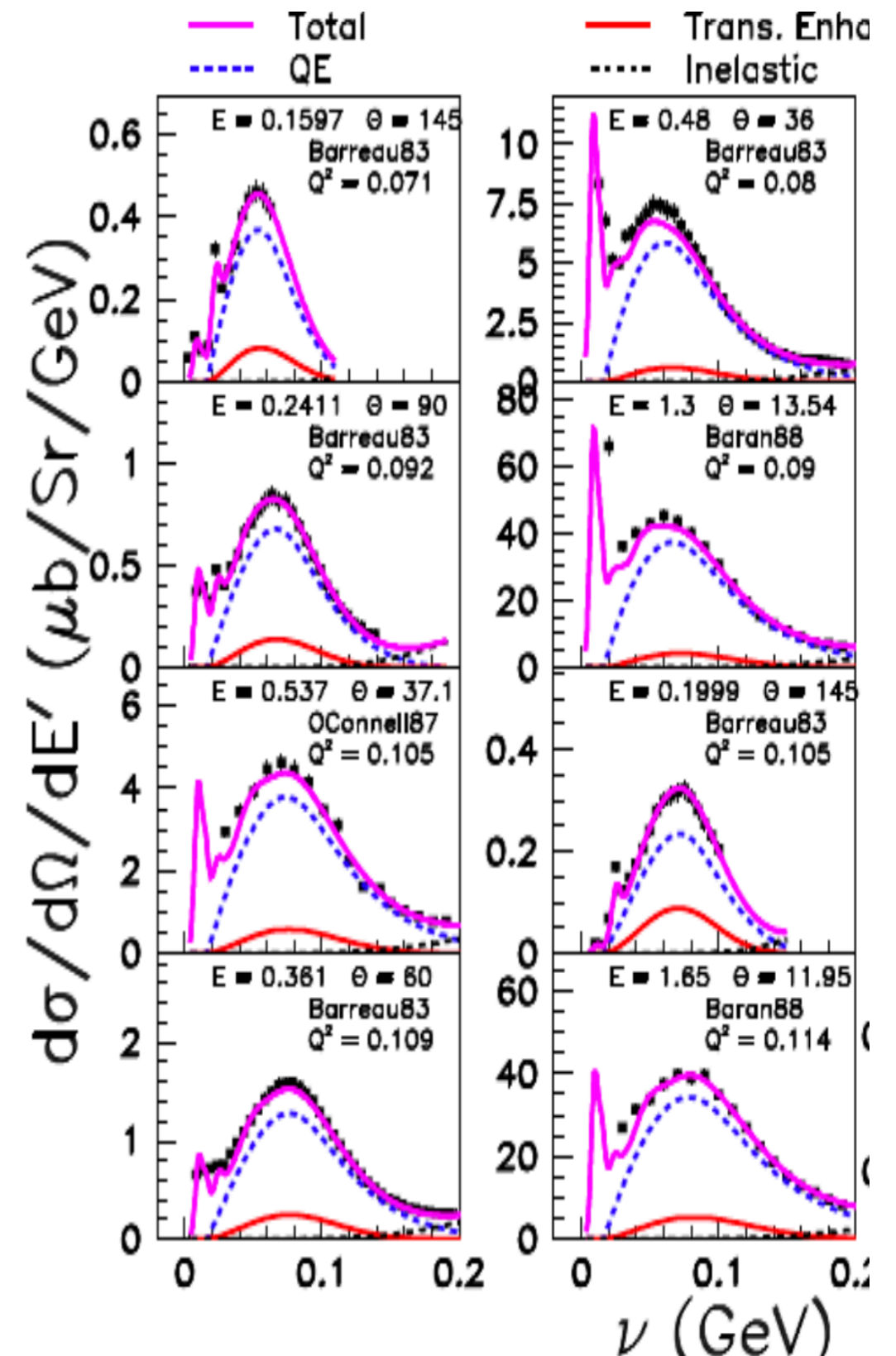
Coulomb sum rule

Arie Bodek

Impressive fit using all (~8000) available inclusive results: Providing R_L and R_T

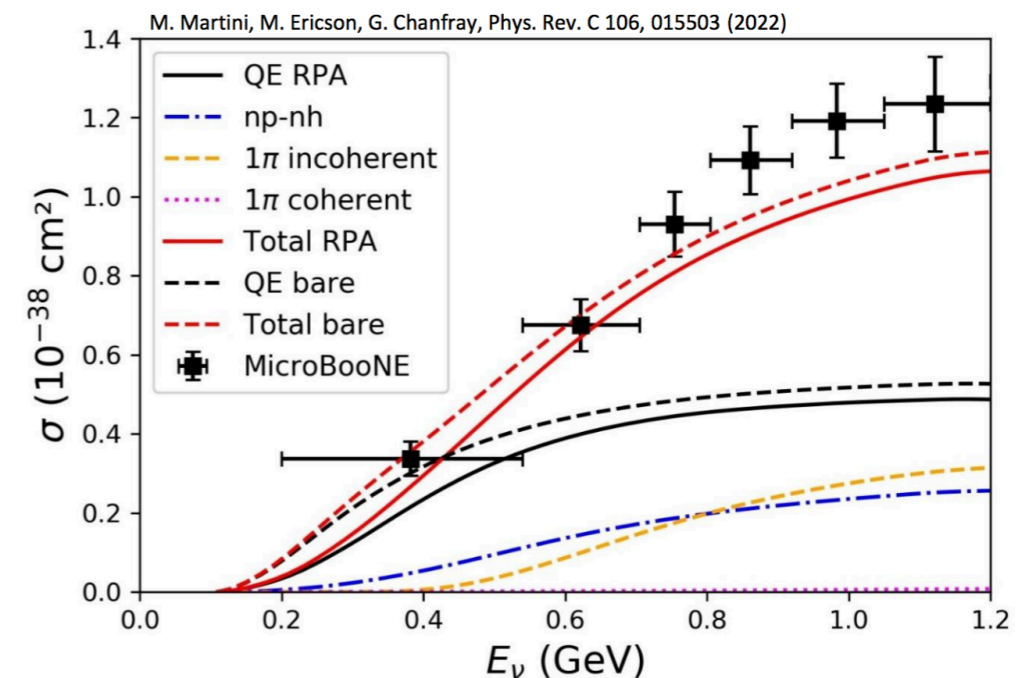
- R_T is enhanced to account for 2p2h
- R_L is Suppressed due to Pauli blocking and requires extra suppression
- At low q the contribution of the nuclear excitations important.

soon to be published to benchmark event generators



The Martini Model showed impressive compatibility with neutrino inclusive and semi exclusive datasets from MiniBooNE and T2K

- MicroBooNE inclusive data shows reasonable agreement for $E_\nu < 0.7$ GeV
- RPA quenching and smearing improves agreement.
- Missing modelling of 2 pion production most relevant to MicroBooNE



Final State Interaction

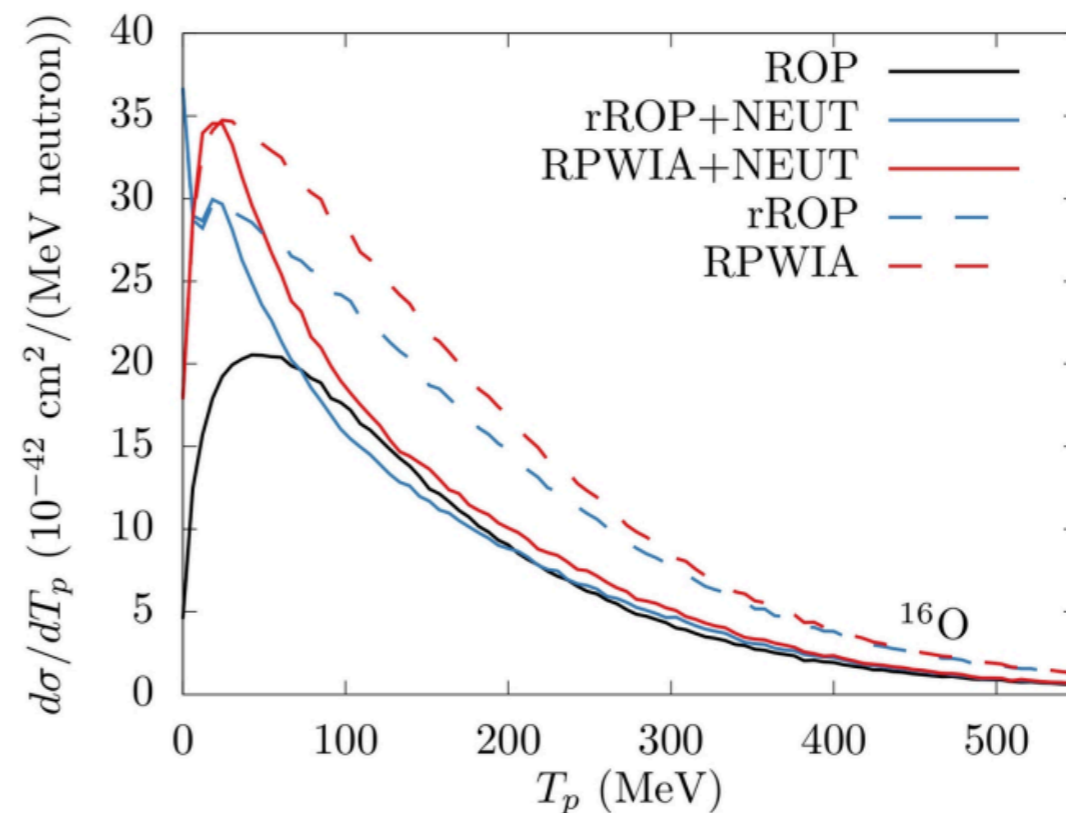
A. Nikolakopoulos

There are various formalism to handle FSI:

The Relativistic Optical Potential (removing nucleons)

The Intranuclear Cascade Model (modelling FSI)

They agree only at large energies



The input to FSI is non trivial, models often include FSI contribution

Event Generators

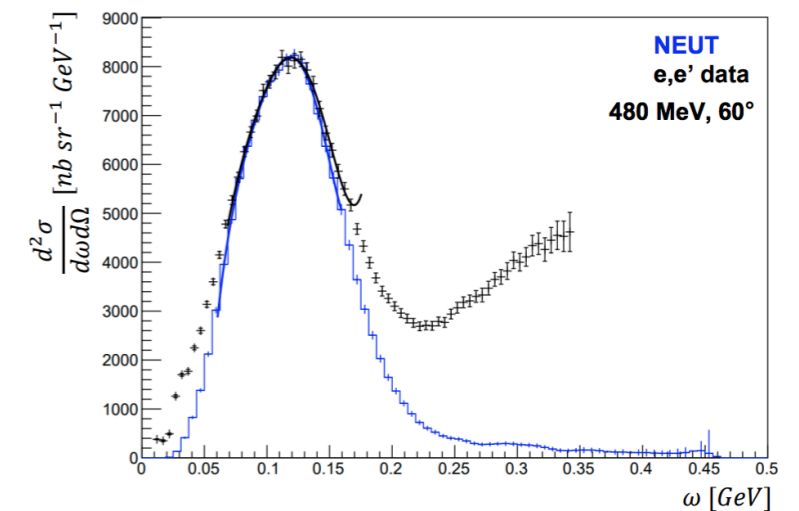
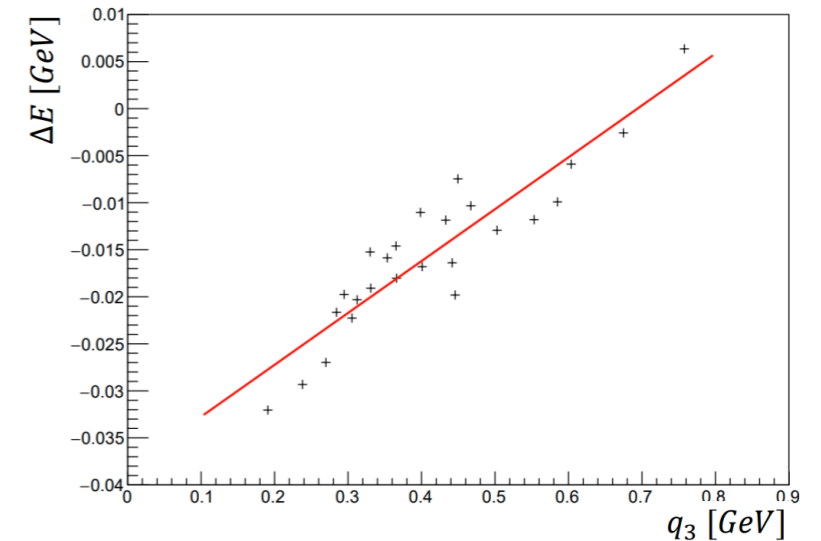
Introducing a new dependency of E_b to q_3 and improving agreement with inclusive results.

T2K ND disfavour the correction.

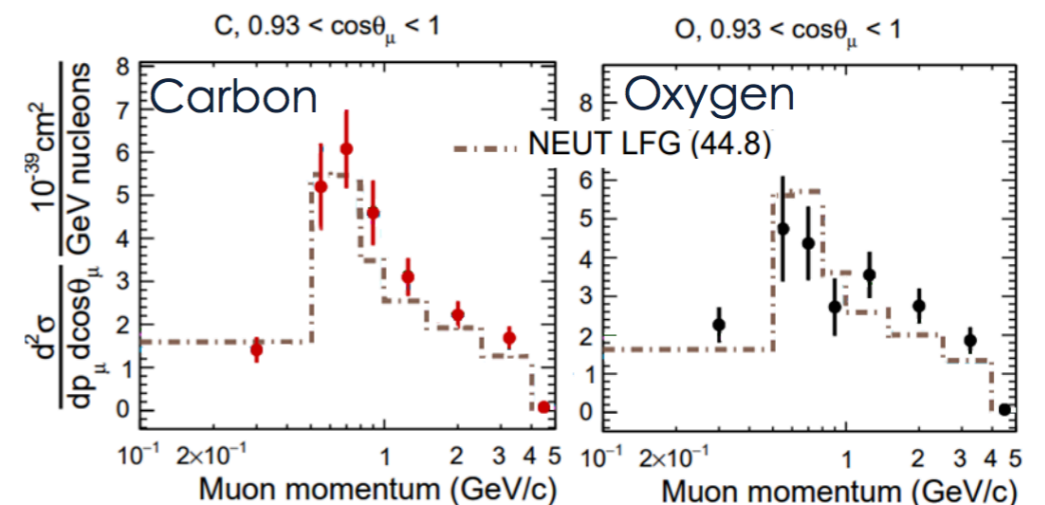
New knobs including: Pion interaction probability in FSI, resonance hadron decay properties

Good agreement with T2K and MicroBooNE inclusive

Also good comparison to T2K CC0 π due to RPA suppression in LFG



T2K CC0 π



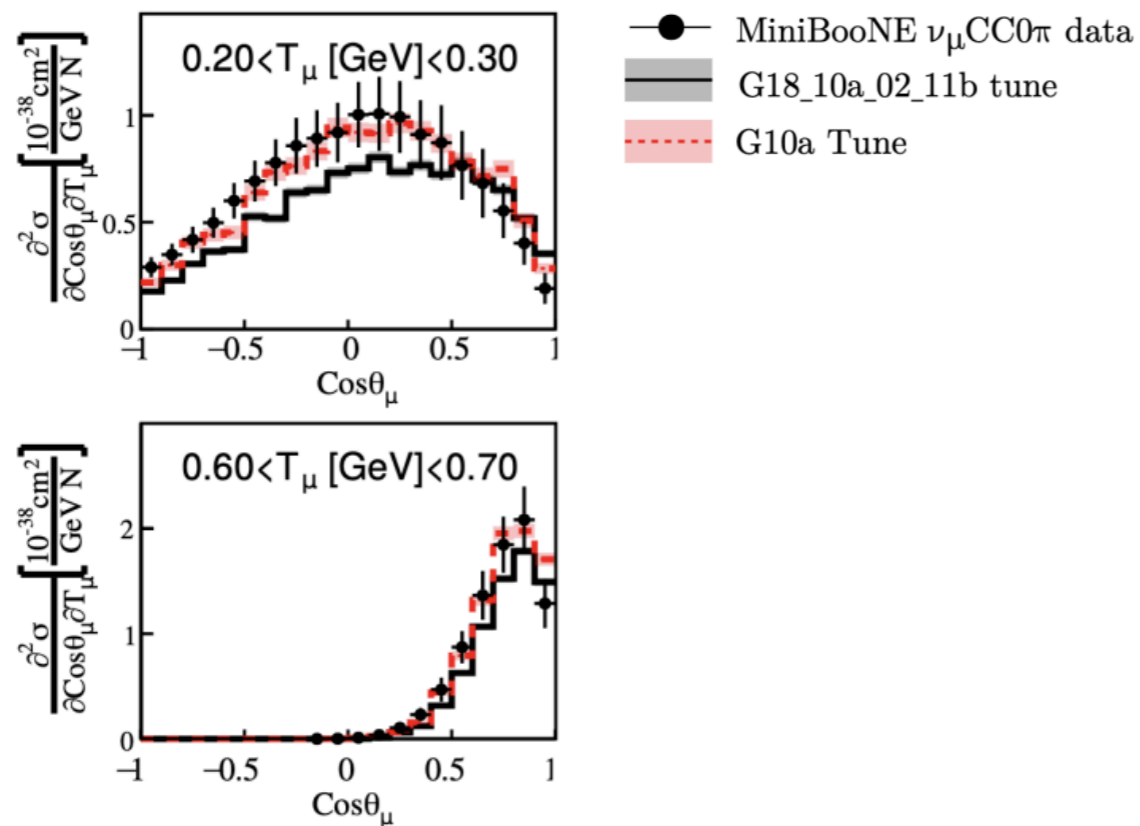
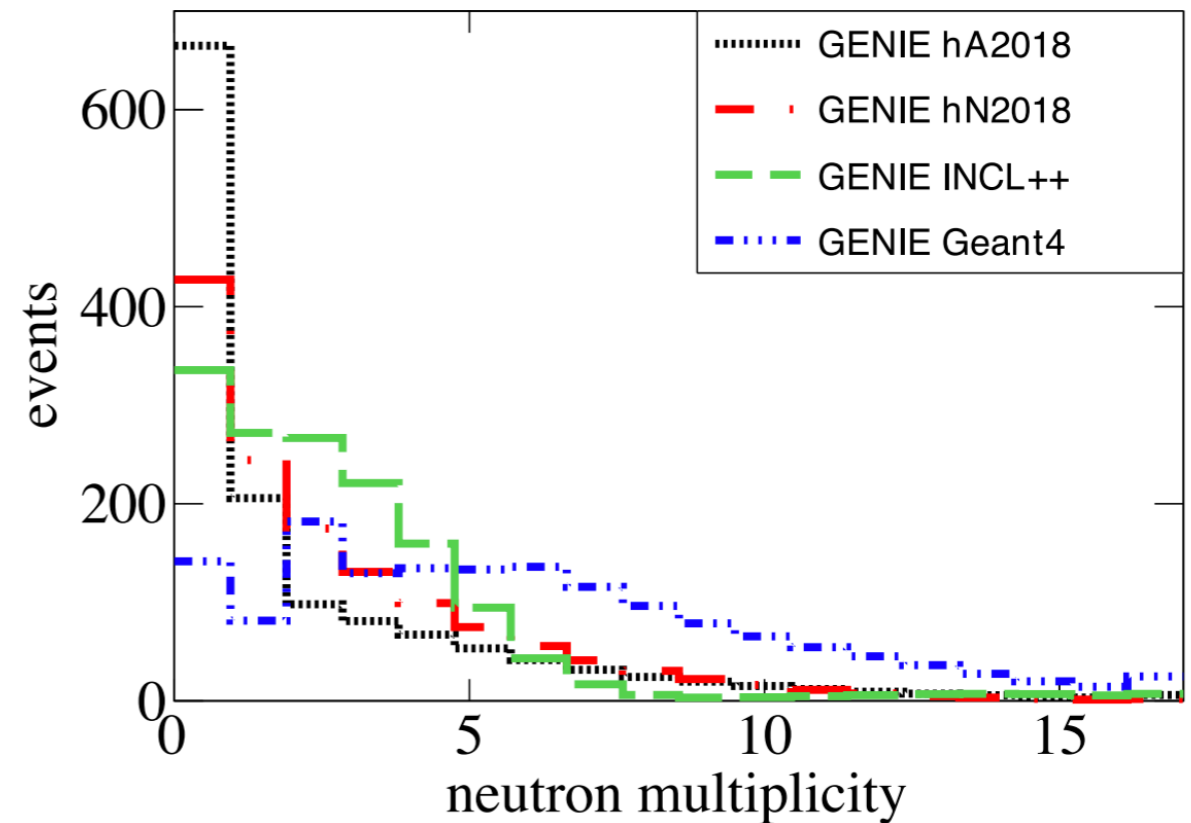
Many new features including:

New FSI models

CEvNS

Correlated Fermi Gas model

new reweighing knobs and more



New CC0 π tune based on T2K, MiniBooNE and MINERvA data

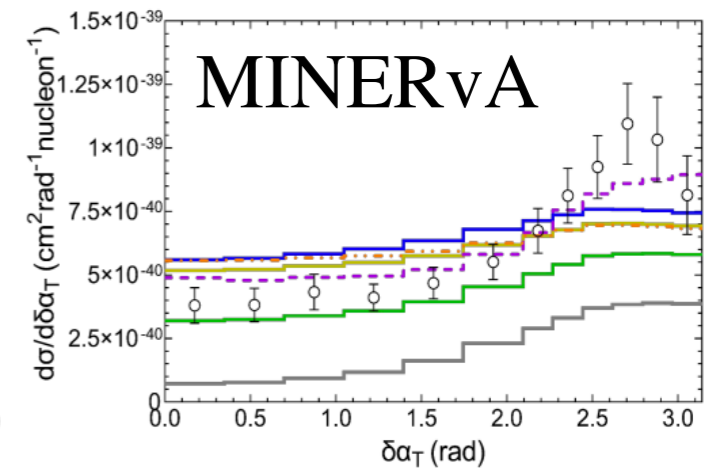
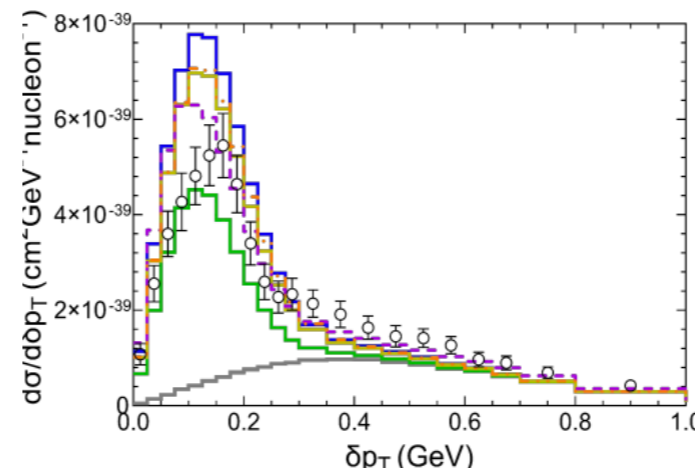
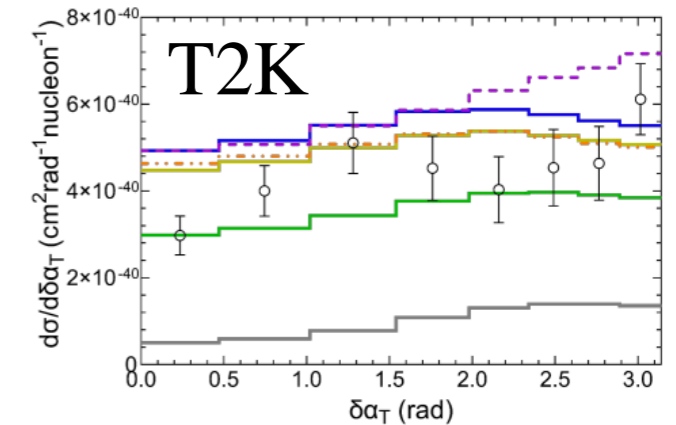
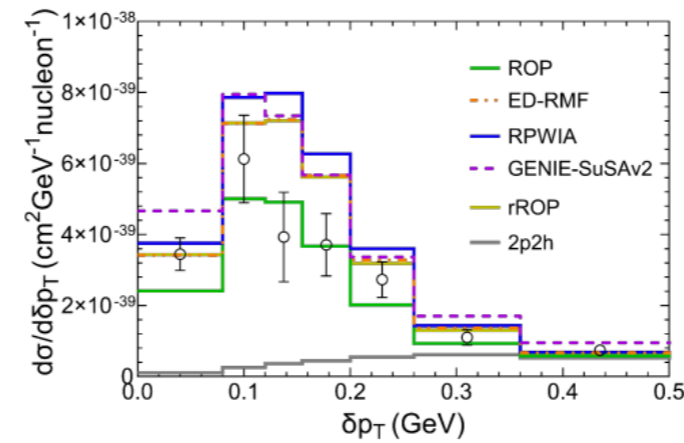
Modification to QE + MEC lead to improved agreement

Test against semi inclusive data

JUAN MANUEL FRANCO PATIÑO

Overview on SuSAv2
implementation in GENIE
compared to semi-inclusive data

Microscopic calculation based on
RMF theory is better at low energy
transfer, where factorization and
SuSAv2 model fail



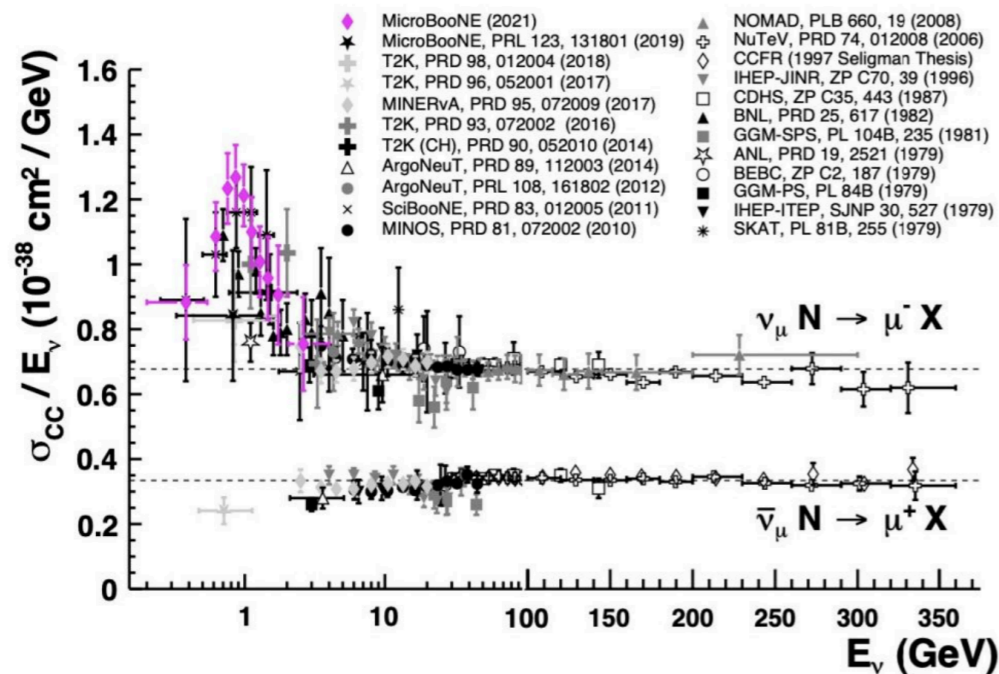
Experimental Results

MicroBooNE

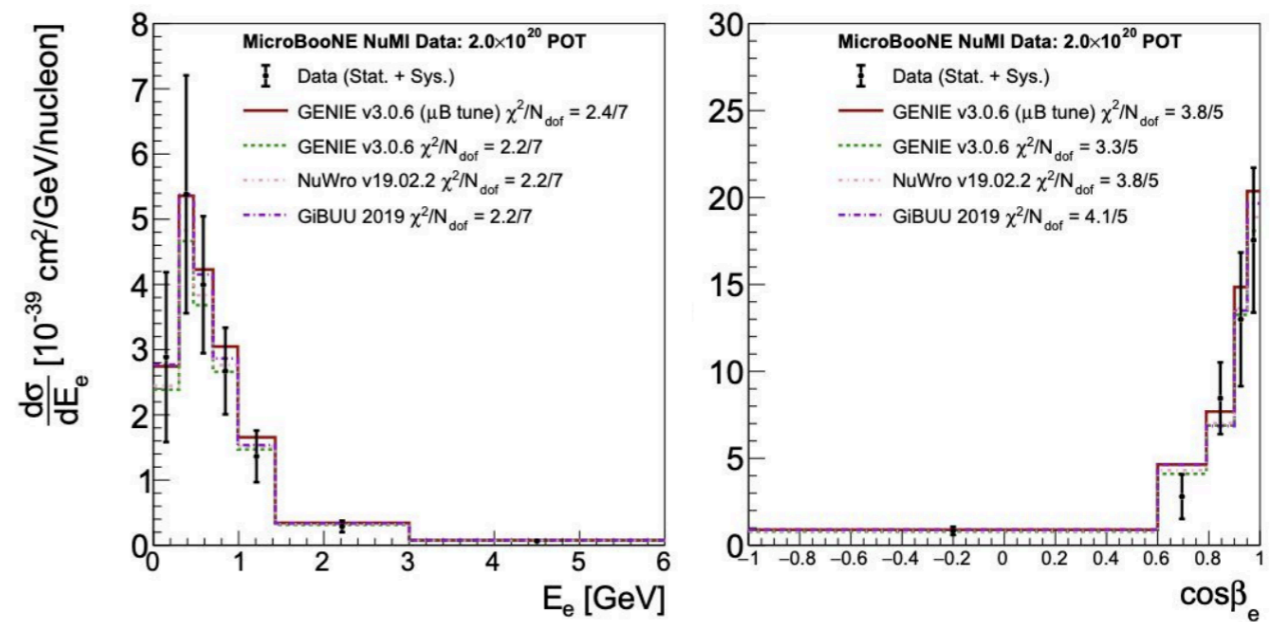
Afroditi Papadopoulou, Elena Gramellini

Plethora of new CS measurements with largest sample on Argon
cross checked with 2 reconstruction methods

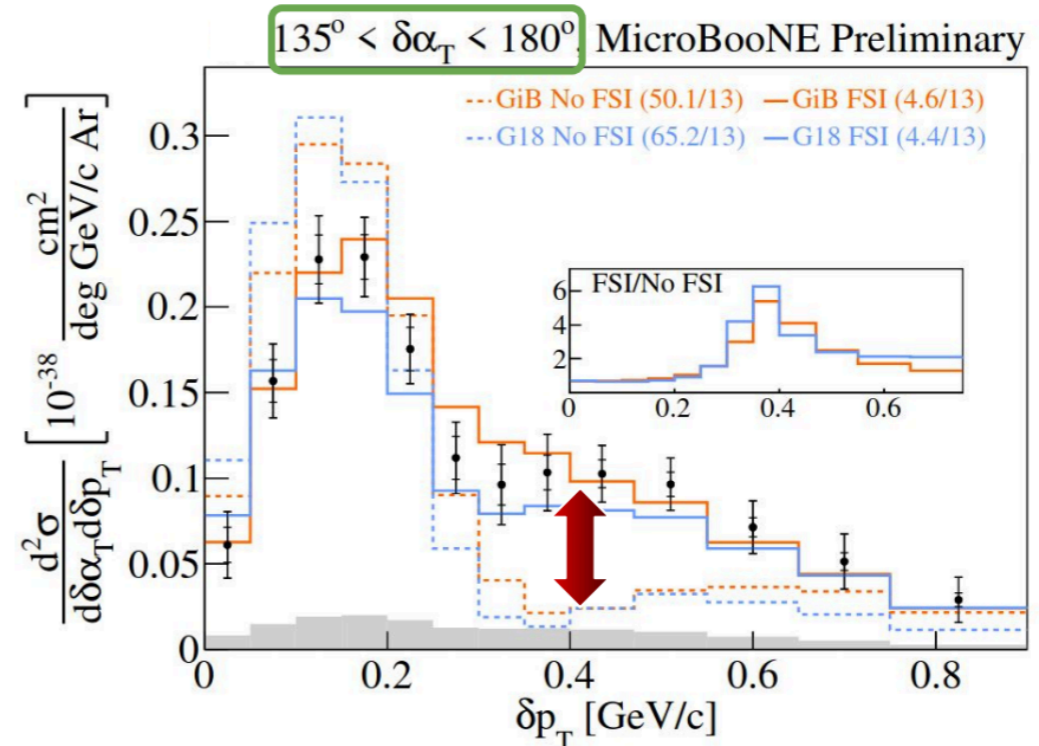
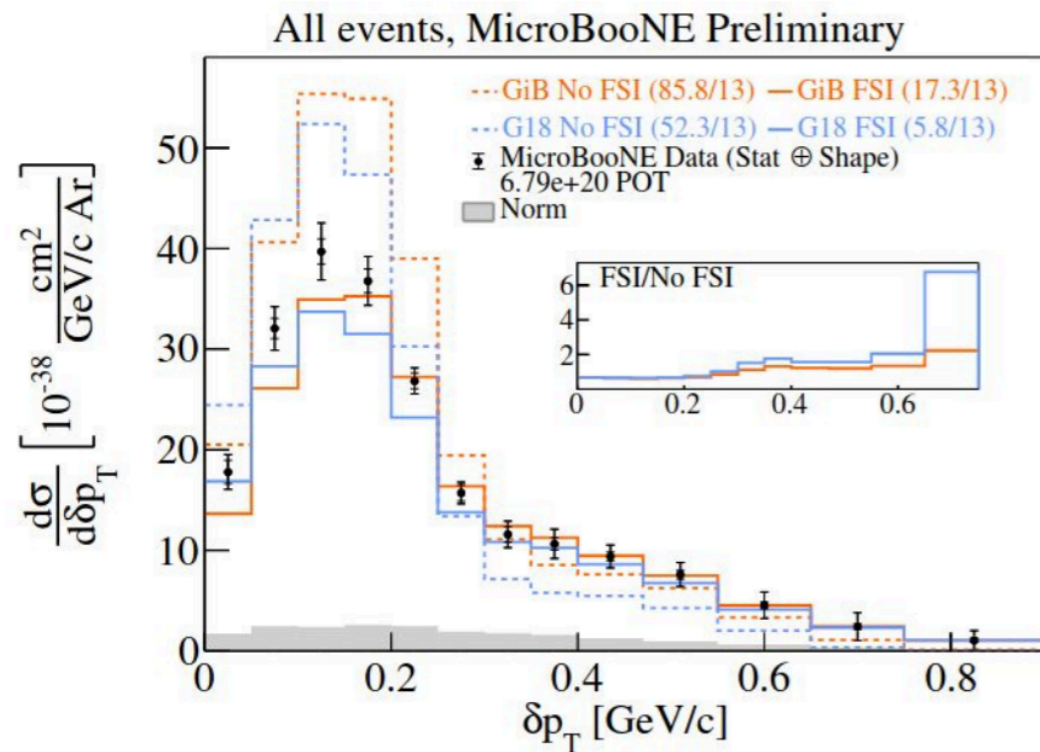
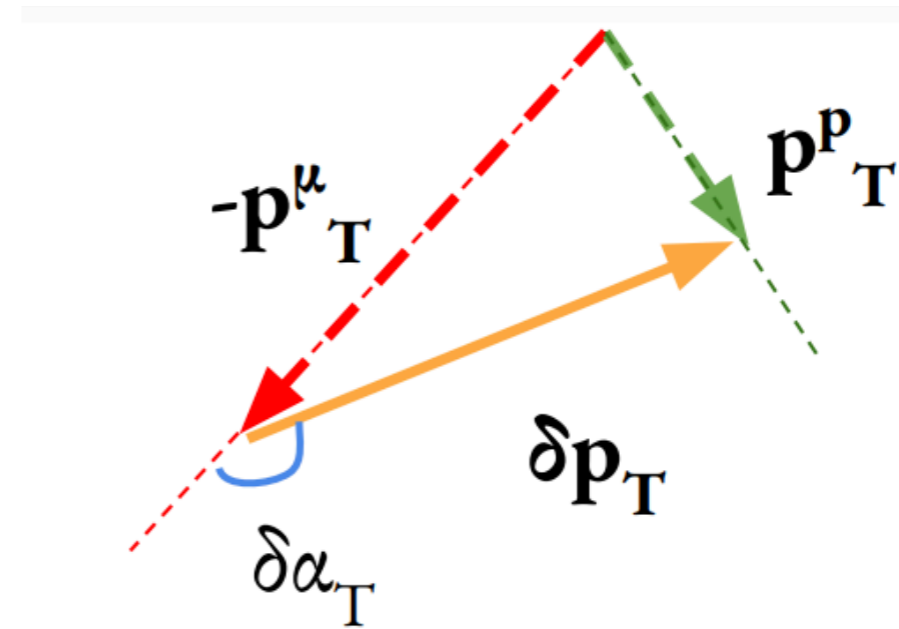
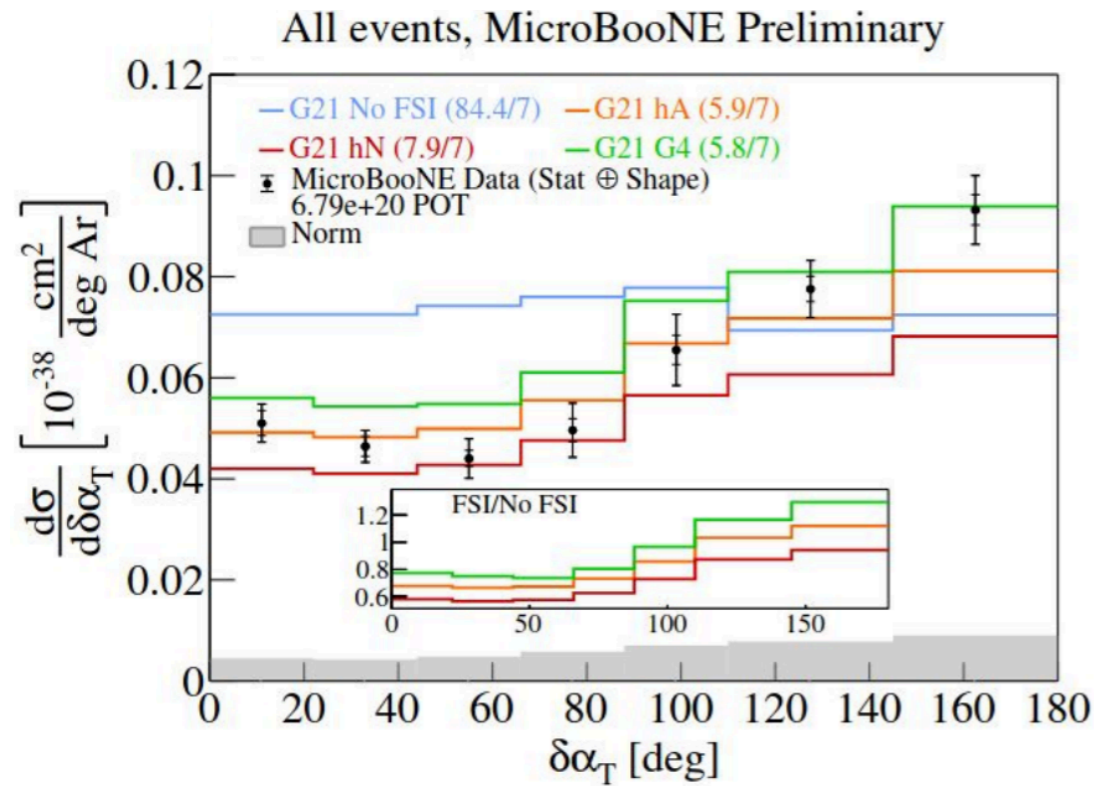
Inclusive ν_μ from BNB



ν_e from NUMI



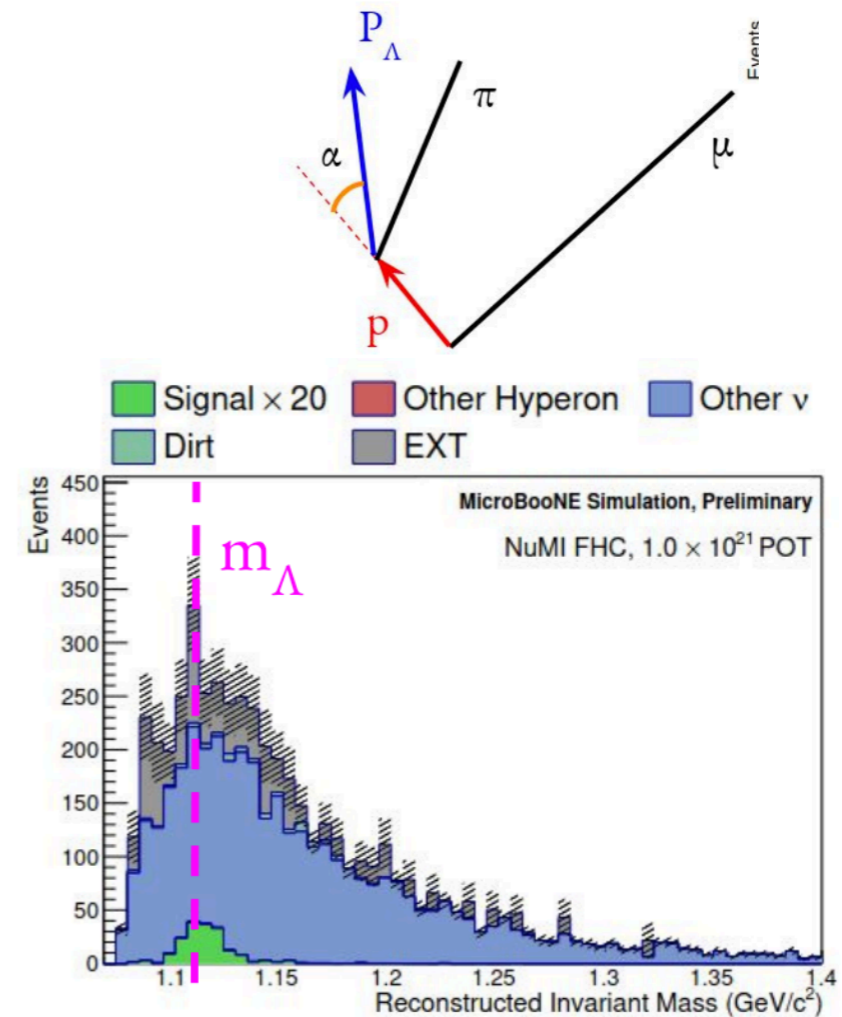
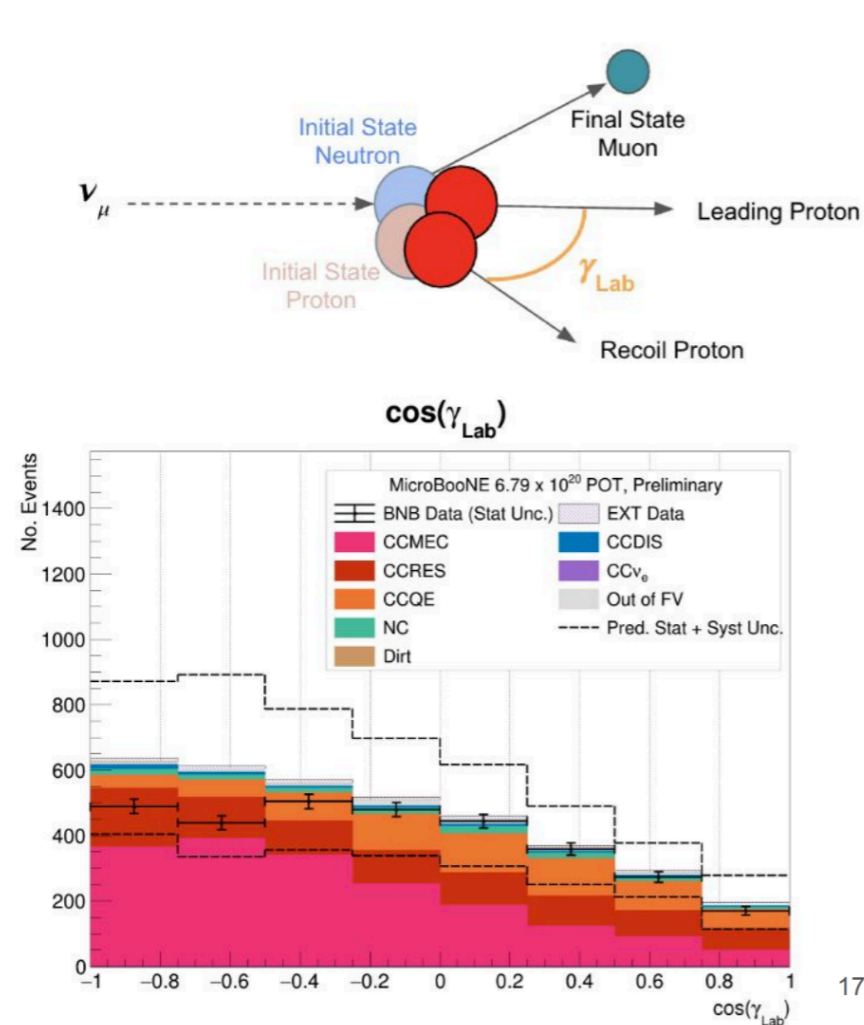
MicroBooNE - TKI



Soon to be published

MicroBooNE

Afroditi Papadopoulou, Elena Gramellini
Chris Thorpe, Julia Book



2p selection favours MEC

+ $1\mu N p 0\pi$, $1e N p 0\pi$, semi inclusive NC with π^0

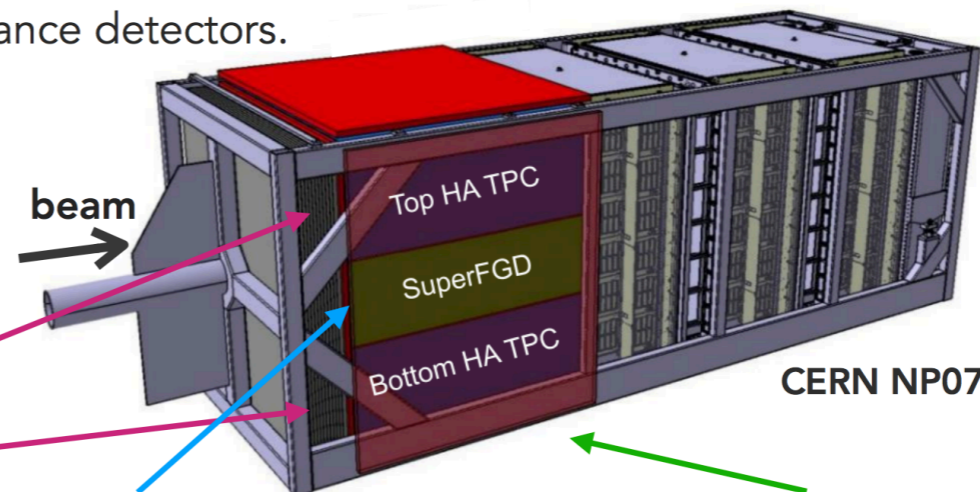
T2K Results

Aoi Eguchi

- Pi-0 detector will be replaced with new 4π acceptance detectors.

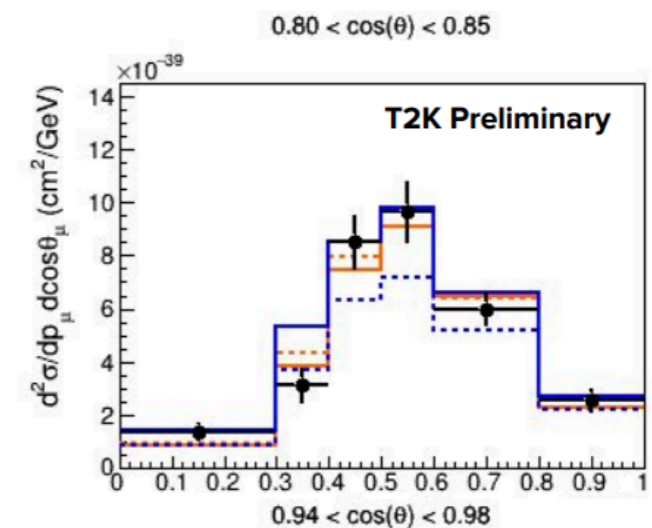
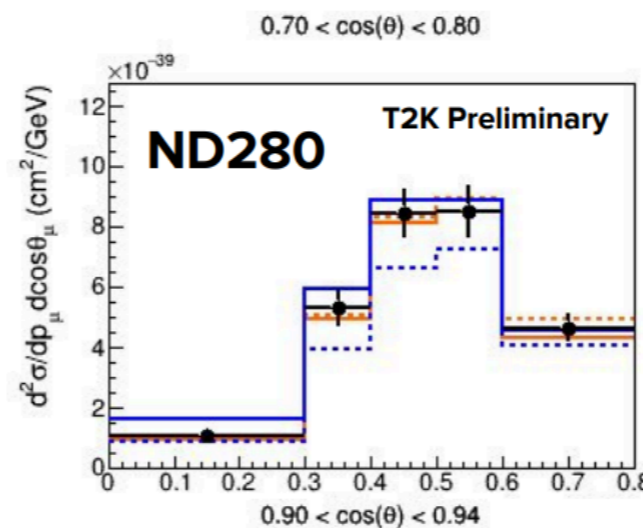
- **SuperFGD** : fully active plastic scintillator.
- **High-Angle TPC**: high resolution tracking of charged particles.
- **Time-of-Flight** : Provide time information.

- Technical Design Report on [arXiv:1901.03750](https://arxiv.org/abs/1901.03750)

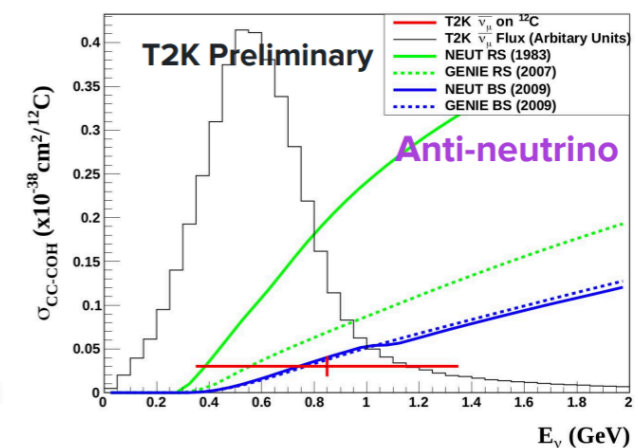
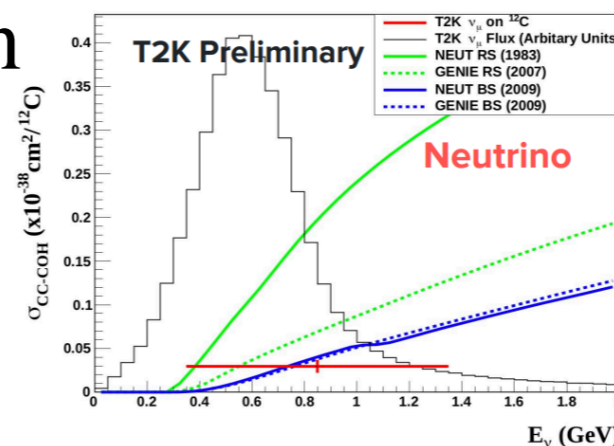


Andrew Cudd

Inclusive

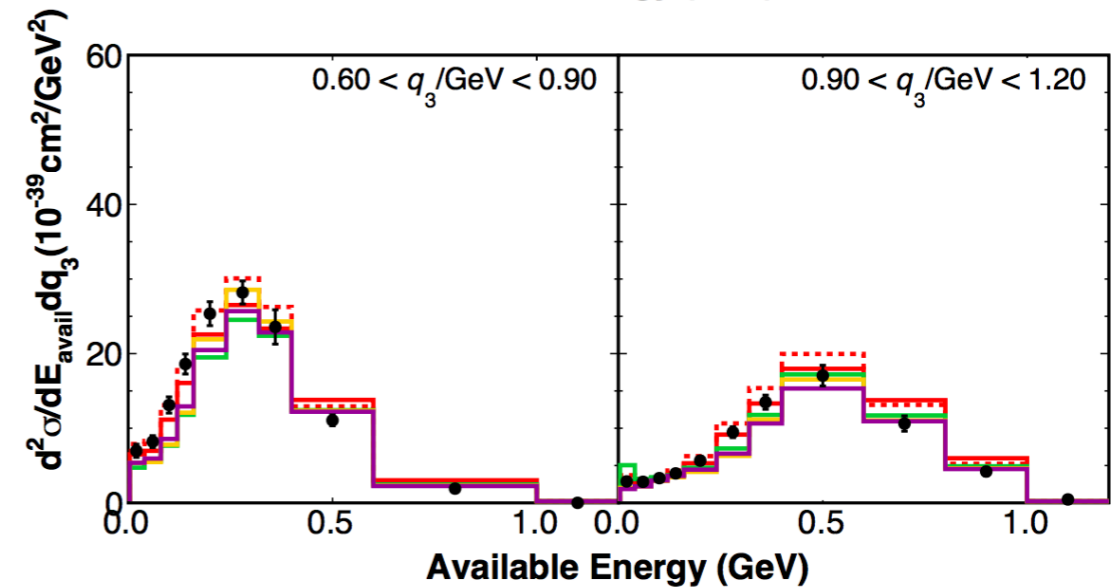


CC coherent pion production

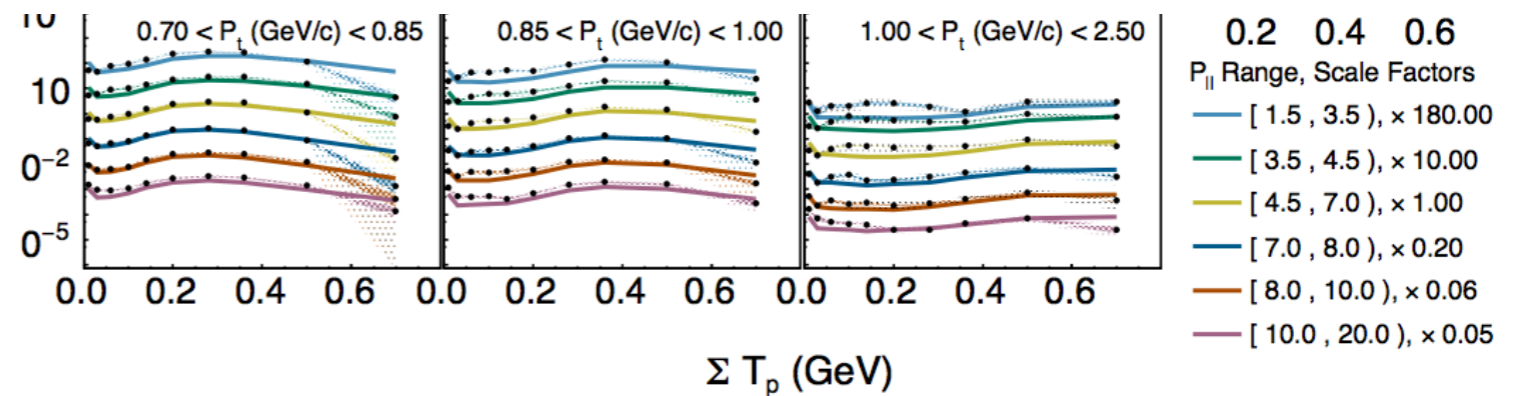




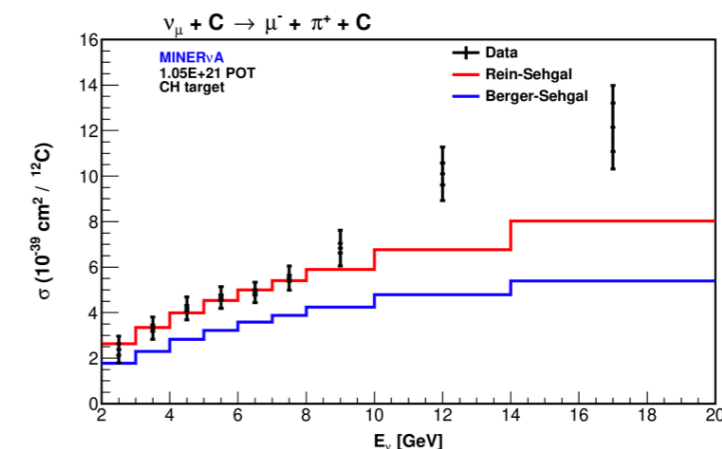
Inclusive Measurements



> 3M CCQE events



Coherent π^0 production important as ν_e background. Disagreement with models



NOvA - $\bar{\nu}_\mu \text{CC} \pi^0$

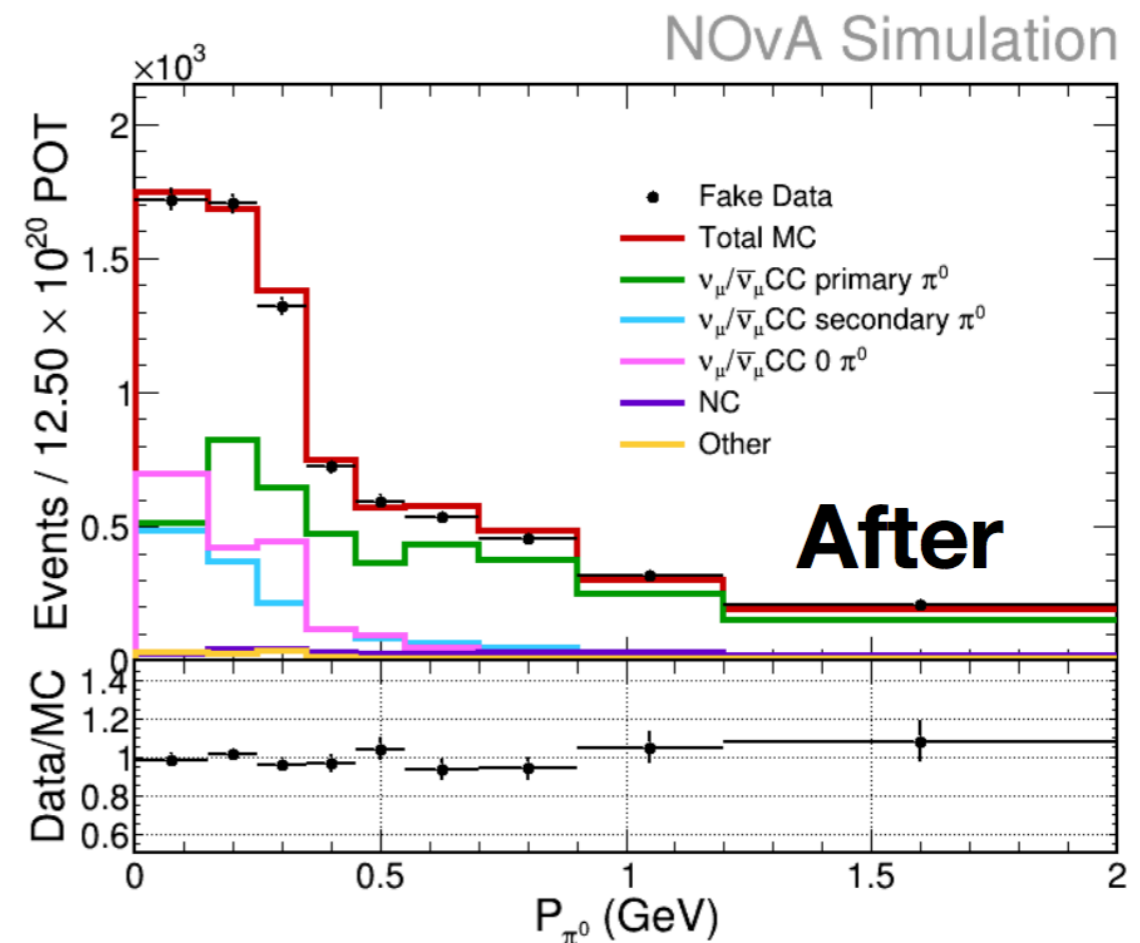
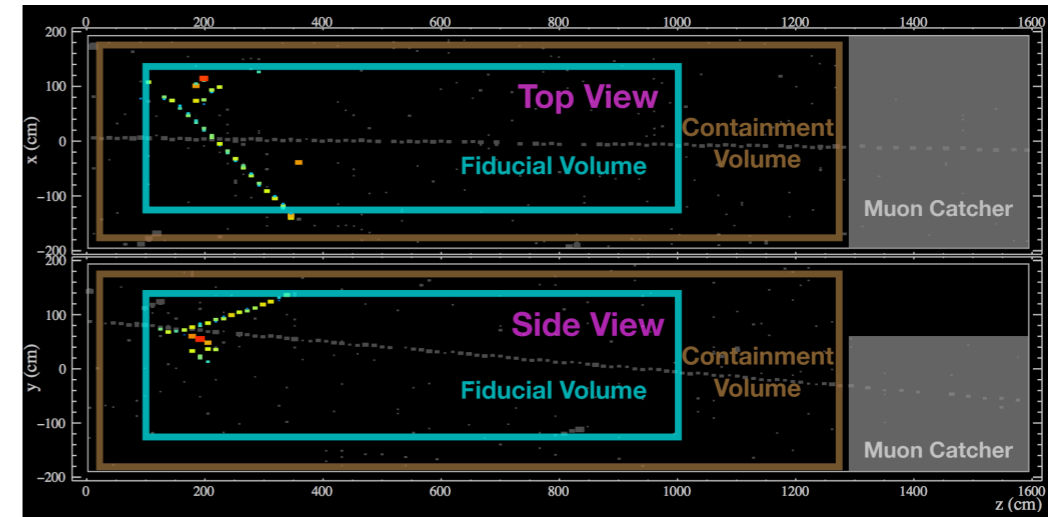
Fan Gao

High statistics for this
unprecedented analysis

EM shower selection using CNN

A data-driven template fit has
been developed to estimate BG

Finalising unfolding and
systematic uncertainty estimation



Various Constraints

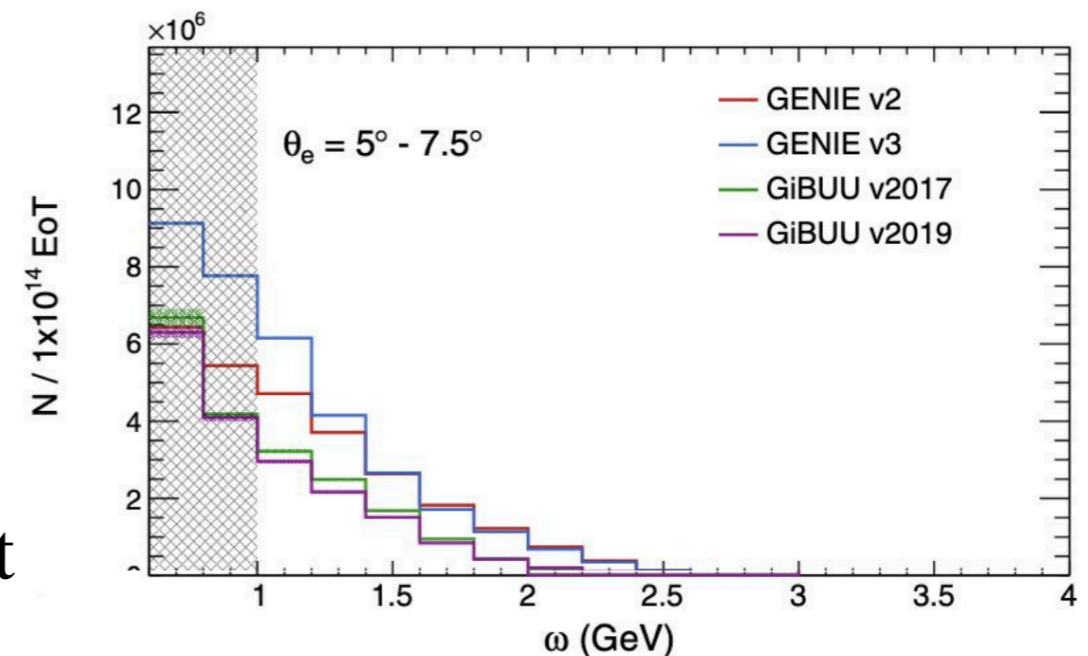
Cross Section Constraints via e scattering

Wesley Ketchum

A DM detector for the benefit on neutrino

Promising capabilities for:

- Great forward angle coverage
- μ/p separation
- neutron detection
- Exact pre-vertex energy measurement



Interesting expected phase space

Stay tuned for news from test beam at CERN

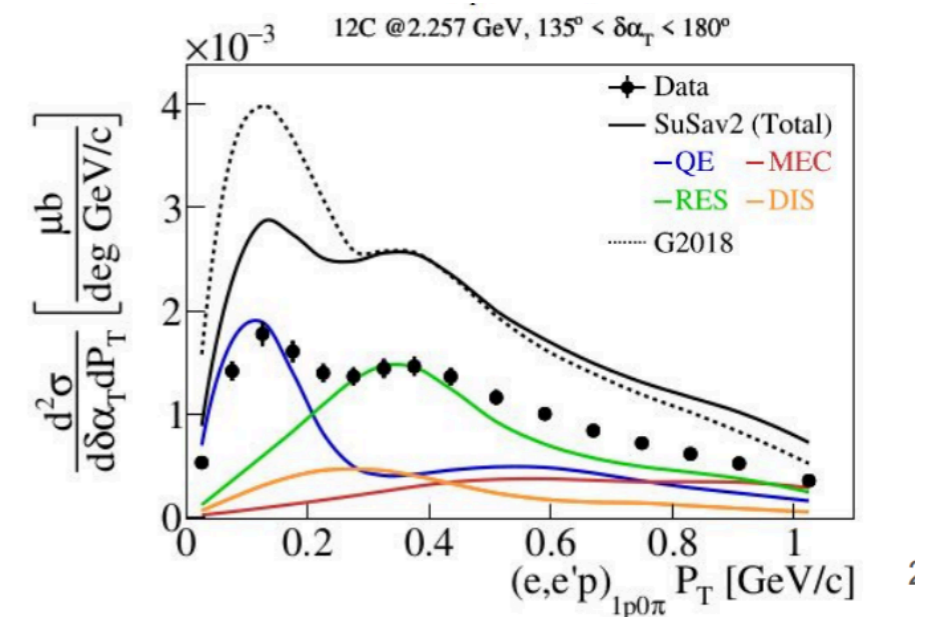
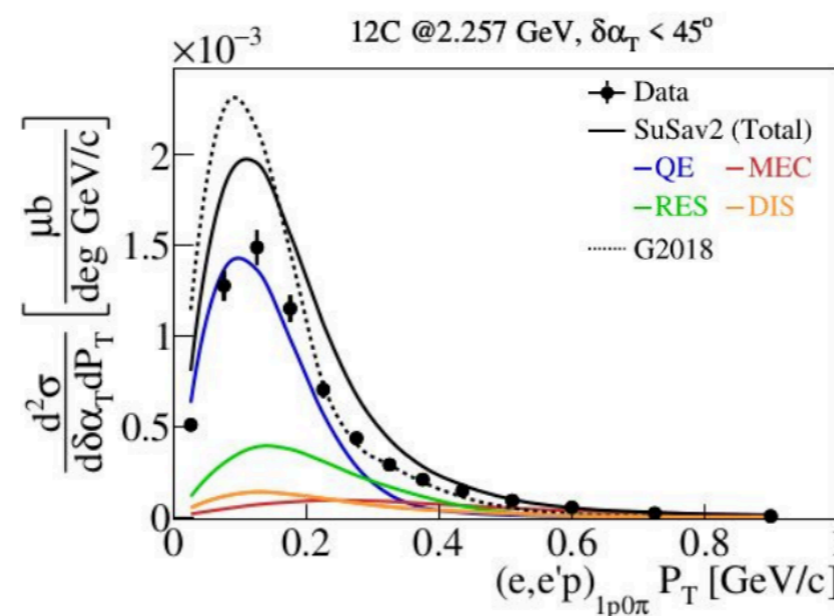
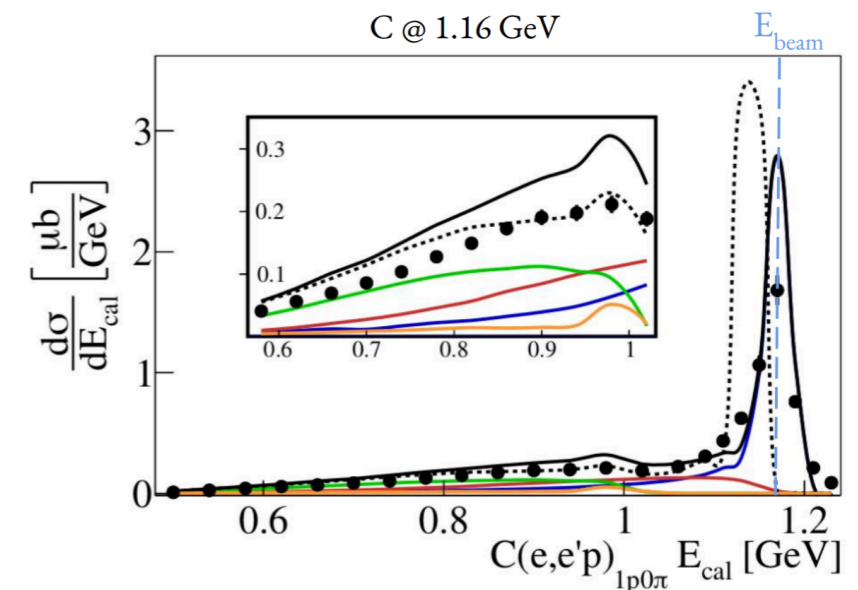
Cross Section Constraints via e scattering

e4V @ CLAS

Disagreement shown in reconstructed energy

Especially for high energies, heavy nuclei and events with high pT

New results showing differences also in TKI distributions



More to come including neutrons

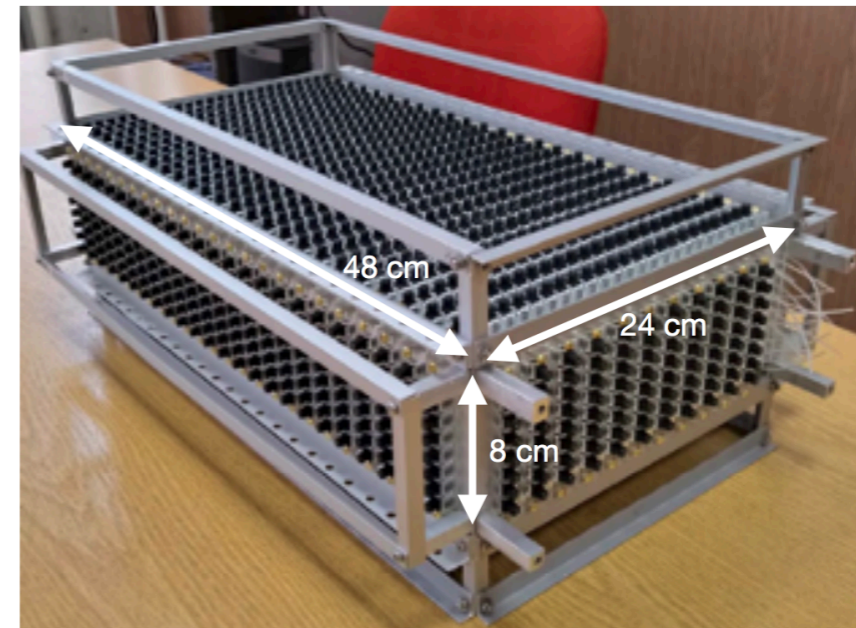
Cross Section Constraints - neutron CS

Ciro Riccio

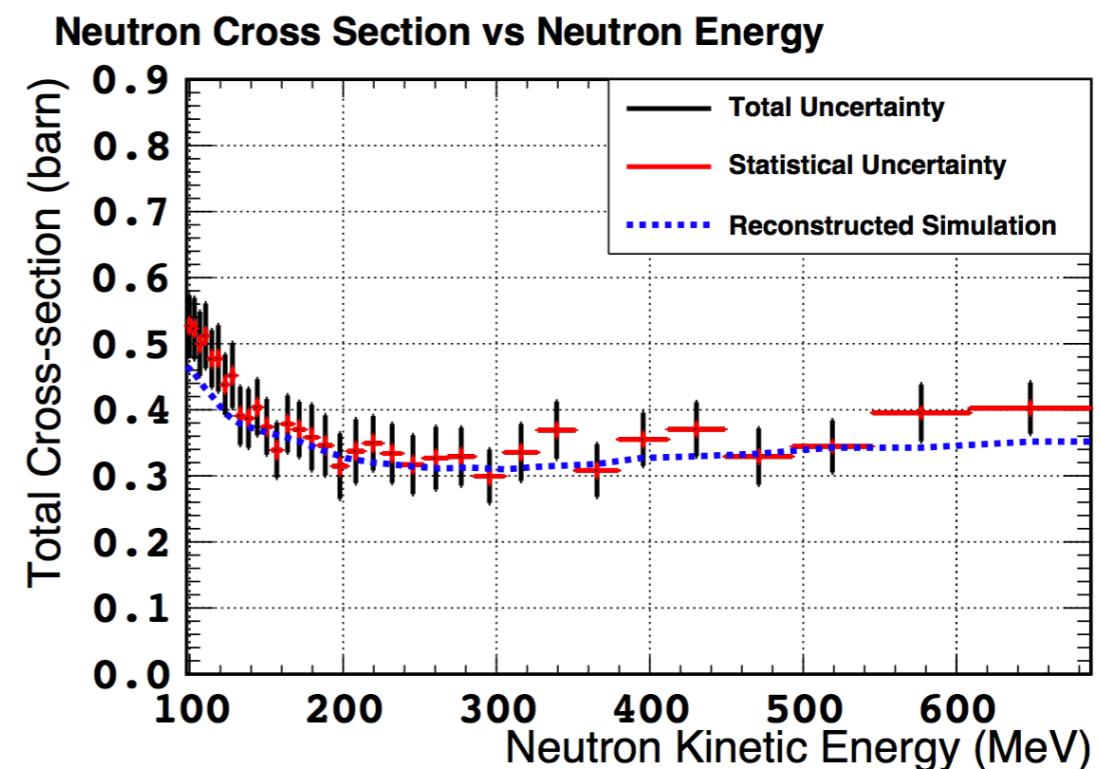
Super-FGD

The 3d cubed scintillator detector

@ 0-800 MeV neutron beam LANL



Measured n-CH cross section -
more to come!



The Accelerator Neutrino Neutron Interaction Experiment

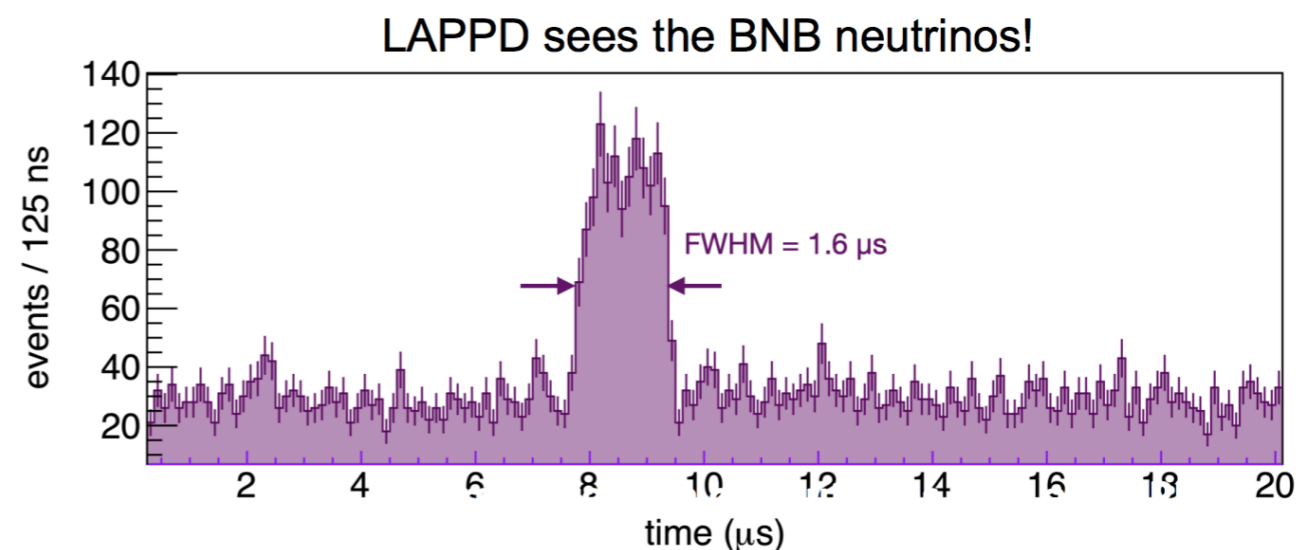
26-ton Gd-loaded Water Cherenkov detector

100 m downstream at the Booster Neutrino Beam line at Fermilab

Measure neutron multiplicity from neutrino-nucleus interactions

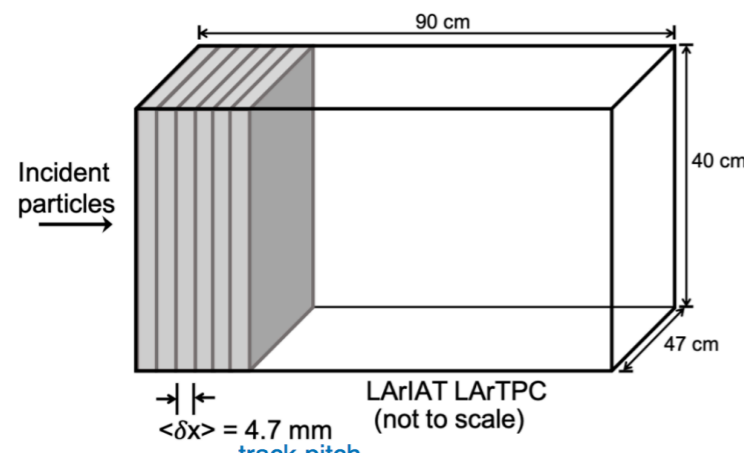
Deployed LAPPDs Micro-channel Plate-based fast-timing photodetectors
and WbLS - Water-based Liquid Scintillators

Seeing neutrinos!



Towards measuring pion argon cross section

Cross section extraction based on LArIAT method

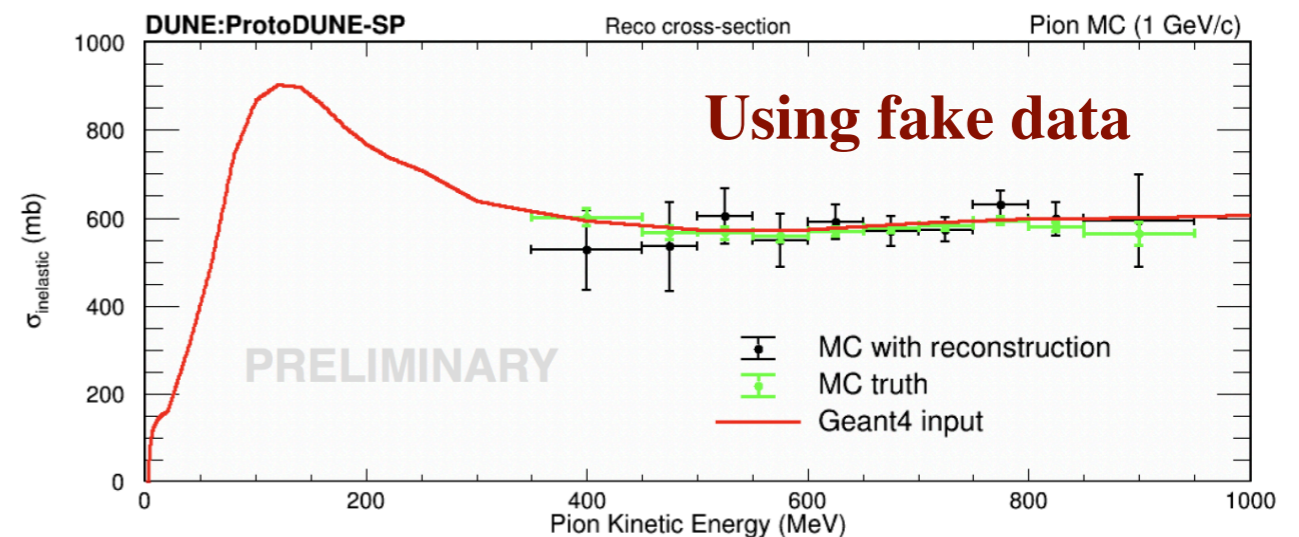


$$\sigma = \frac{M_{\text{Ar}}}{\rho \delta x N_A} \ln \left(\frac{N_{\text{inc}}}{N_{\text{inc}} - N_{\text{int}}} \right)$$

- M_{Ar} is the mass of an argon atom
- N_A is the Avogadro constant
- ρ is the density of liquid argon
- δx is the thickness of the slice
- N_{inc} is the number of incident beam pions in a slice
- N_{int} is the number of beam pions which have interaction in a slice

Also using stopping muons to constrain

Stay tuned for data!



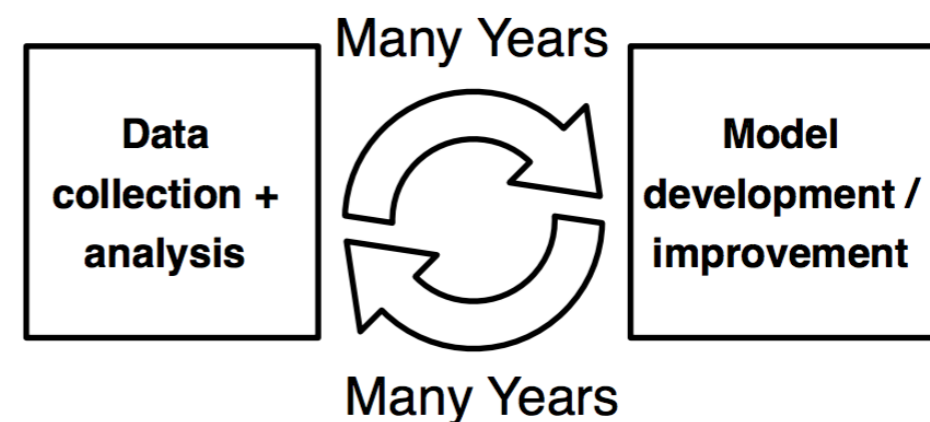
Tuning as a way of life

Jon Paley

Following an overview on recent tunes
Paley brought interesting food for
thought:

- We will likely need to “tune” our predictions for a very long time to come. Note, GEANT has been doing this for **decades!**

- The data-driven model-improvement cycle is extremely long, often on the time-scale of of a decade. DUNE would really benefit if we can get started now on getting high-quality ν +Ar xsec data at energies at and above the Resonance. (Note: the 2x2 demonstrator at FNAL is likely insufficient.)



- We should not forget that hadron+A cross section uncertainties are critical too!
 - Modeling of secondary interactions (typically done via Geant) is important for event selection efficiency calculations and hadron energy reconstruction.

Flux Constraints

Jon Paley

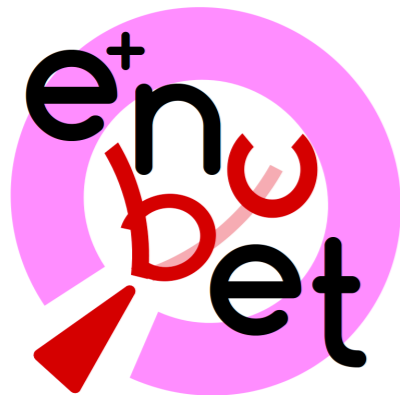


Table top hadron production to improve neutrino flux prediction @ FNAL test beam facility

There's already available data!

Currently collecting more to improve elastic and quasi elastic scattering measurements

phase 2 place EMPHATIC on a motion table downstream of spare NuMI target



Claudia Delogu

Monitoring neutrino beam, by measuring leptons from pions and kaons decay

Simulation showing promising results: adding tagger information lower flux uncertainty from 6% to 1%

Currently building a demonstrator - stay tuned for the data

More from NA61/SHINE in WG3

Flux Constraints

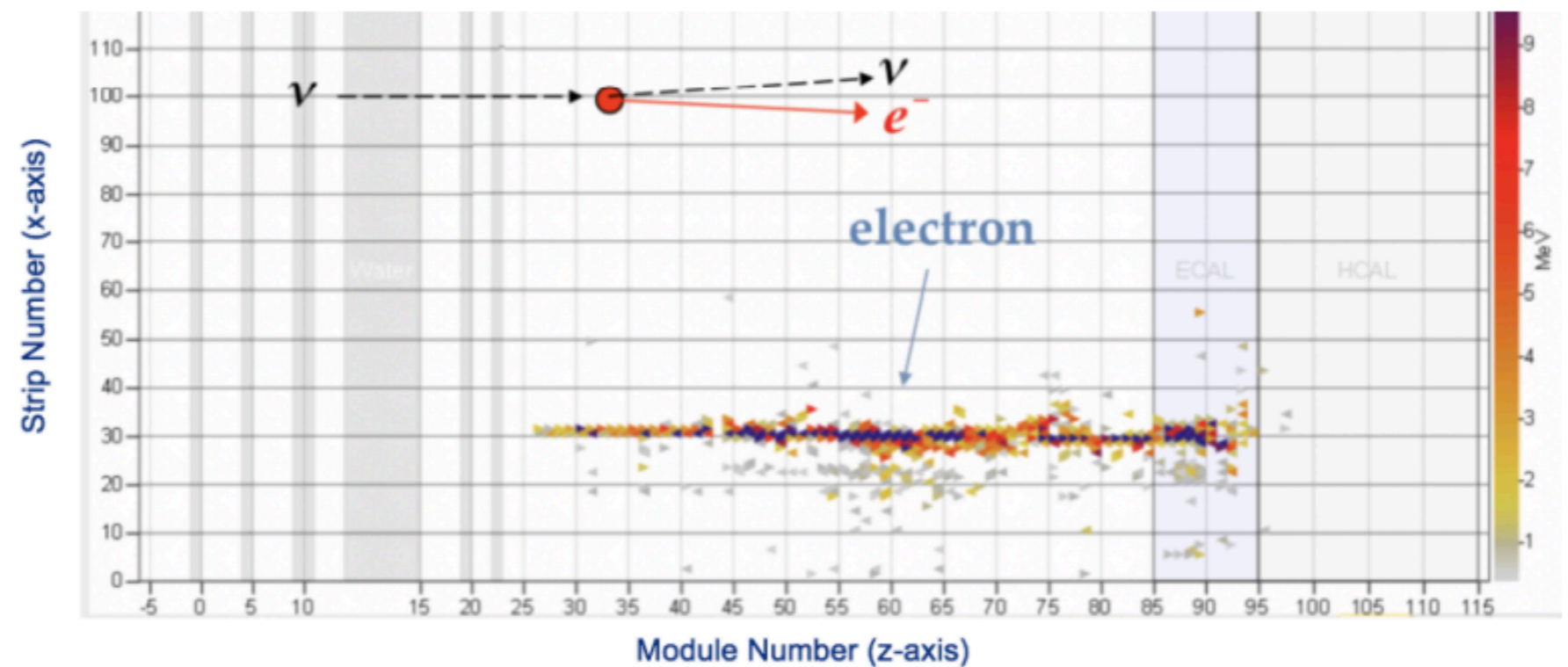
Minerba Betancourt



Using neutrino electron scattering inside MINERvA to constrain the flux:

3.3% in neutrino mode

4.7% in antineutrino mode

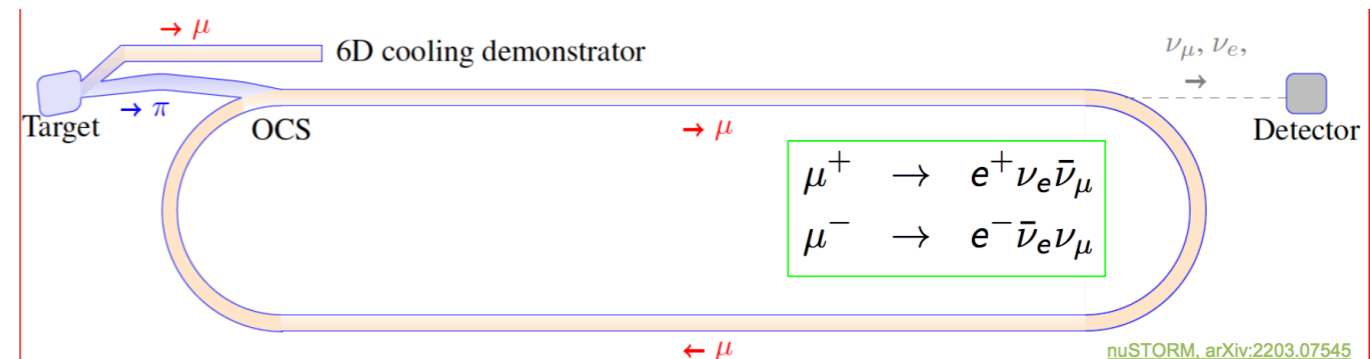


More to come

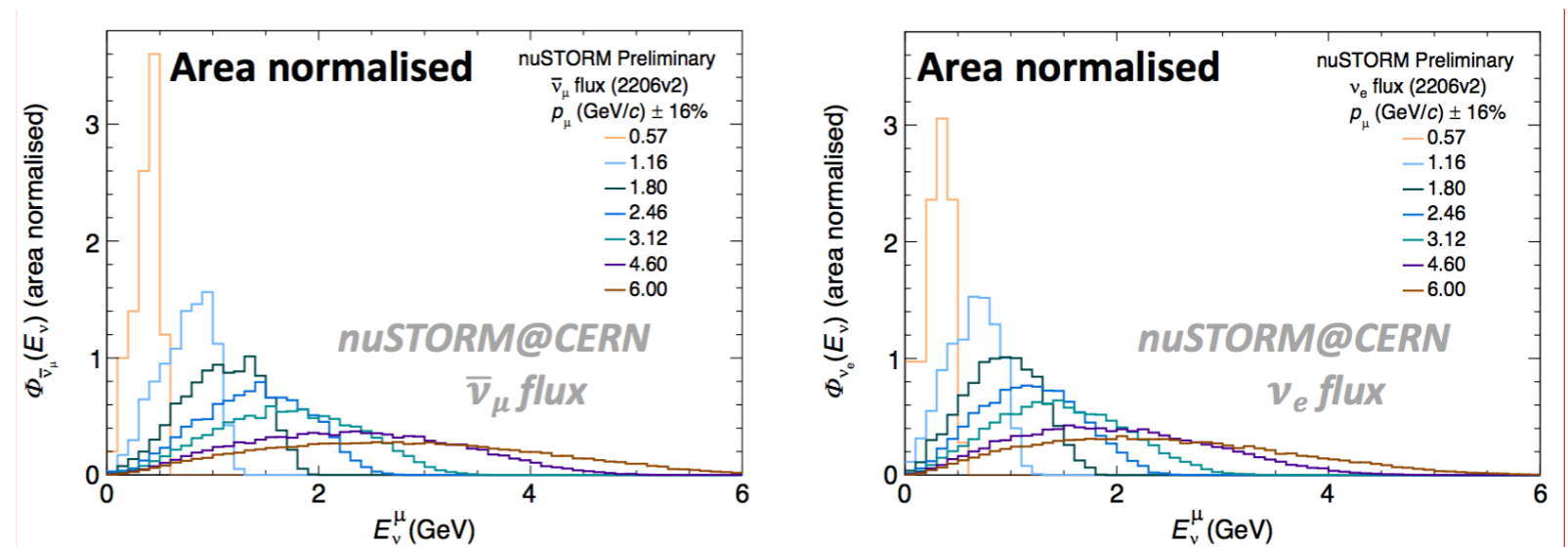
ν STORM - neutrinos from stored muons

Collimated beam of neutrinos with known flux $< 1\%$

for $\%$ level cross section and BSM search



Potential to scan neutrino energy



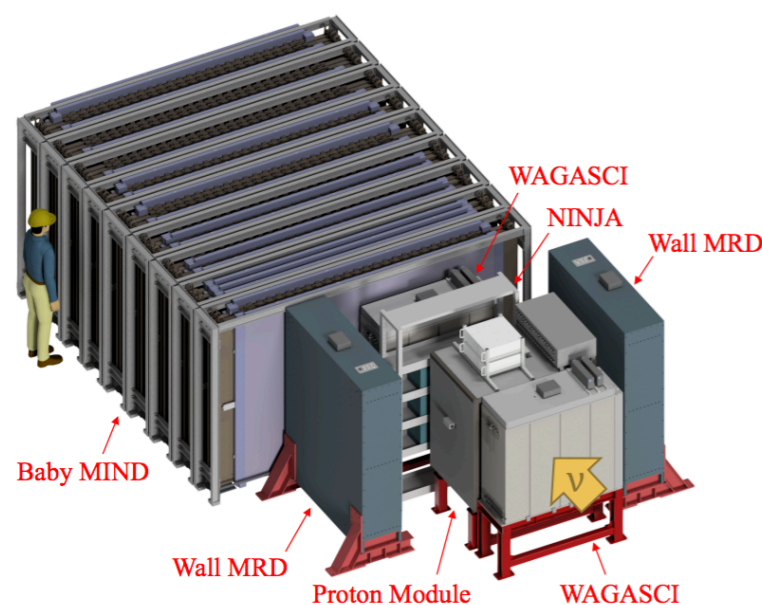
Thinking of a joint facility with ENUBET at CERN

Neutrino Interaction research with Nuclear emulation at J-PARC Acc
low-momentum charged hadrons from neutrino-nucleus interactions

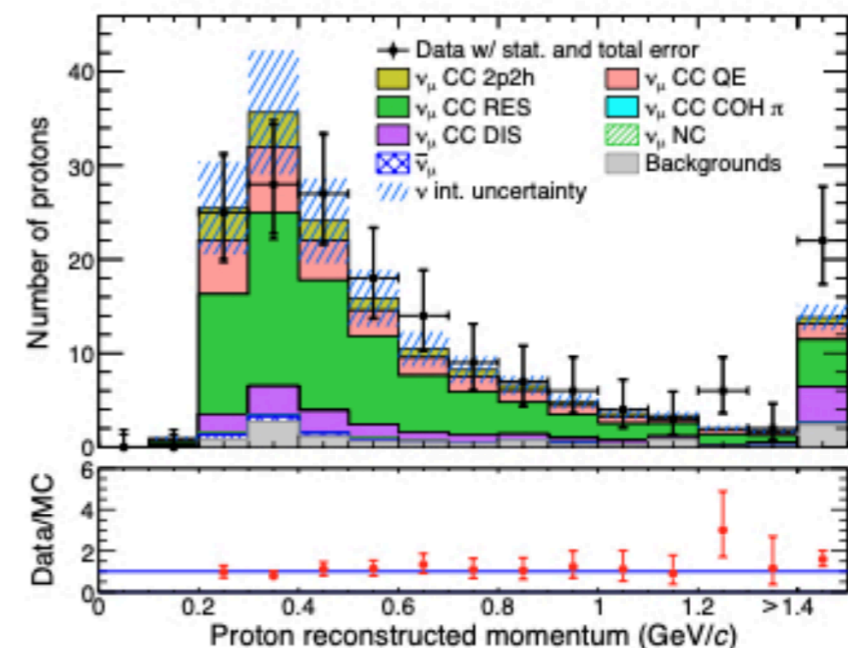
From 2018 pilot run detecting protons from 200 MeV/c!

New measurements on the way

with H₂O, D₂O Fe and CH targets including multiplicities



65 kg iron target run



Study tau neutrino from Ds decay

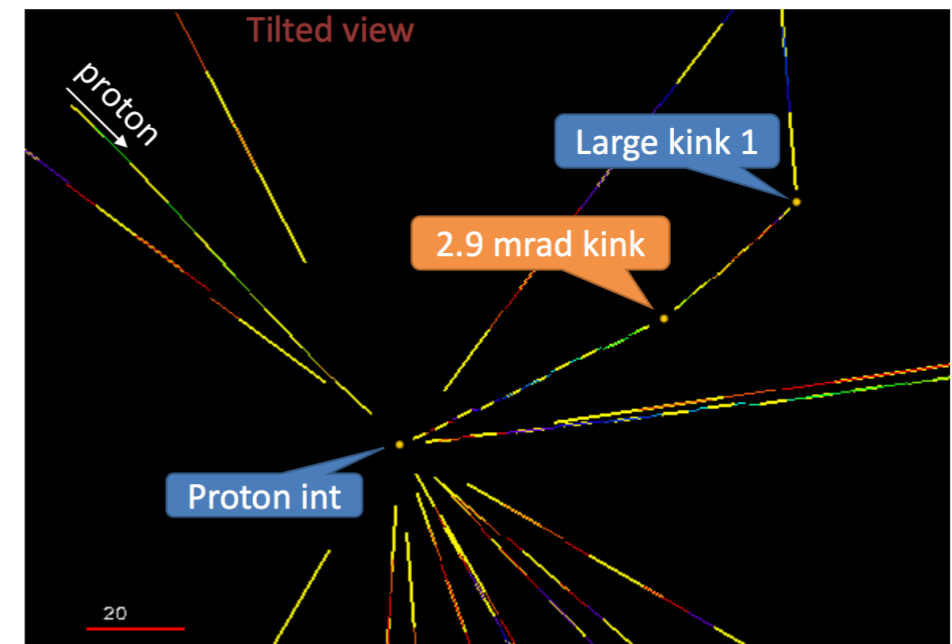
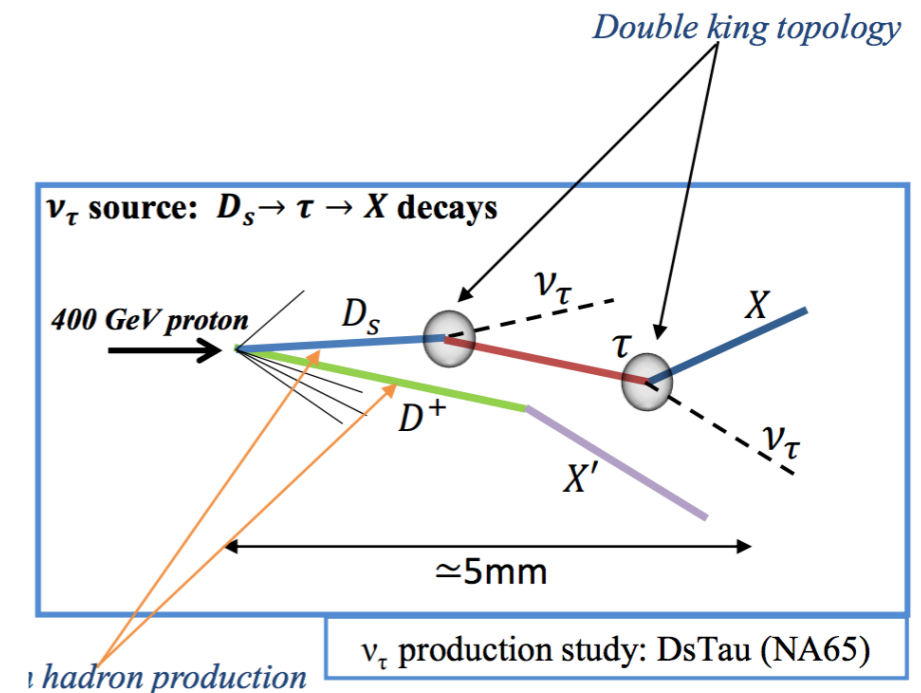
fundamental input to ν_τ experiment list
FASER ν / SHIP

Aims to decrease ν_τ production
systematics

Nuclear Emulsions interlaid with
tungsten/molybdenum (lead/tungsten)

Data run 2021-2022

Expecting ~ 8 M events

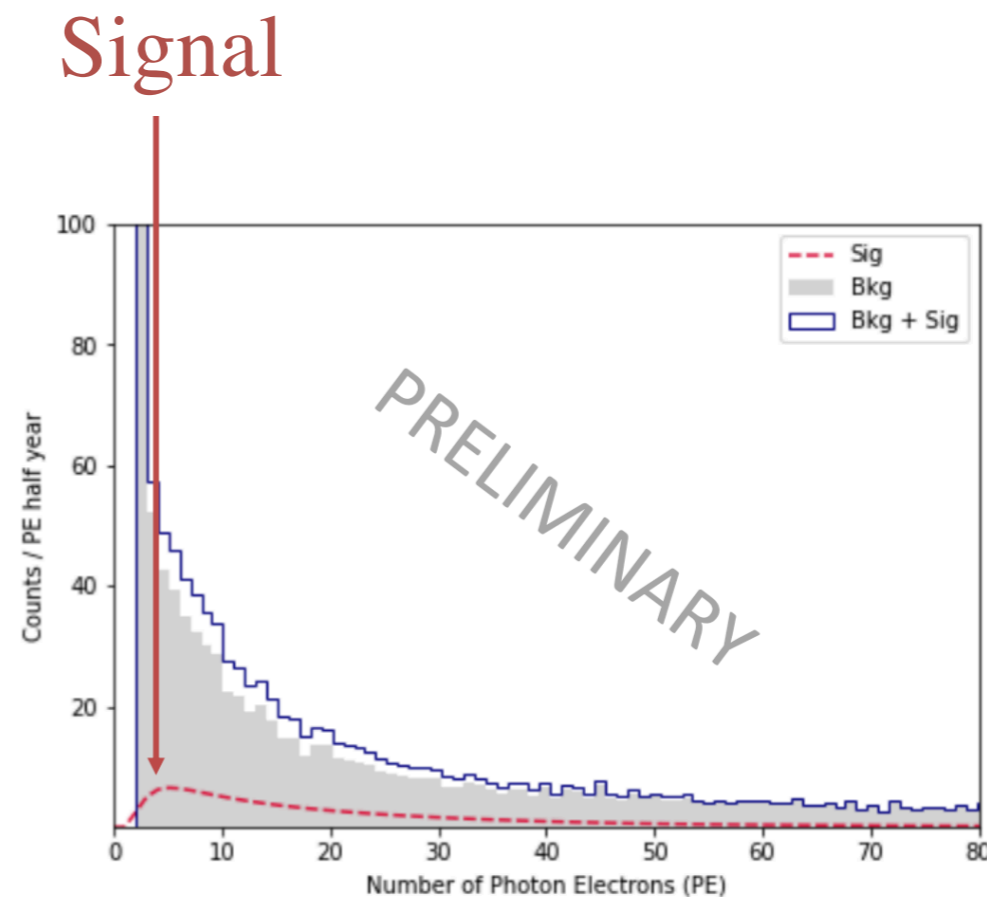
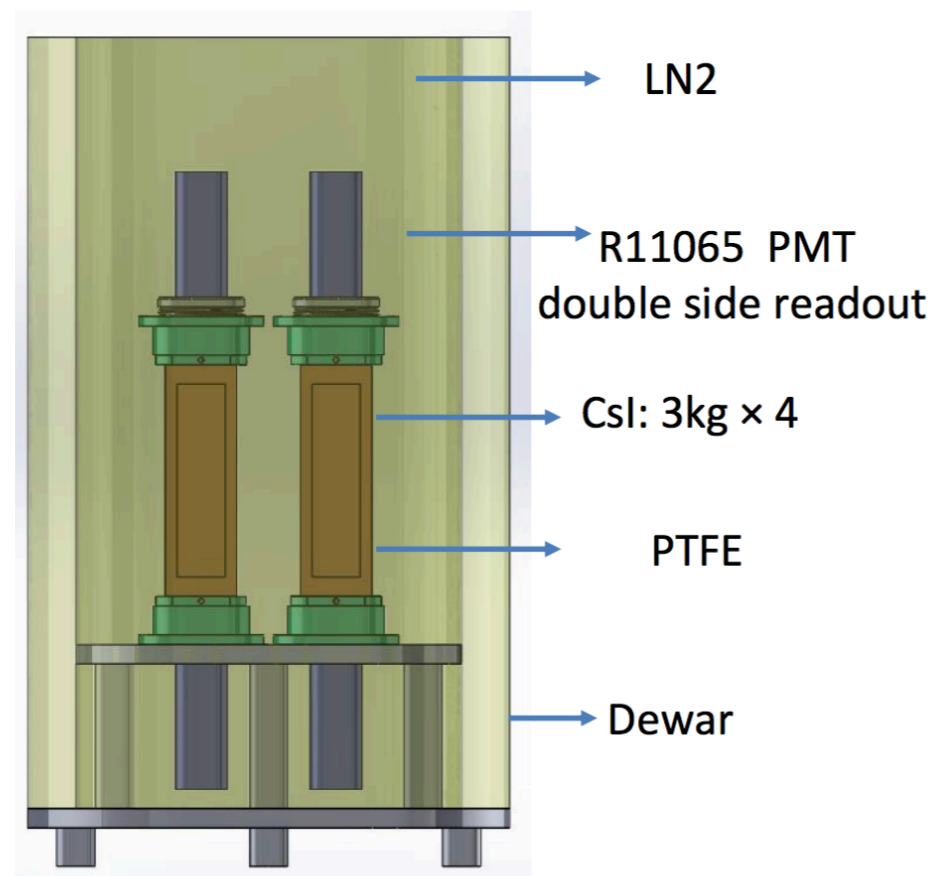


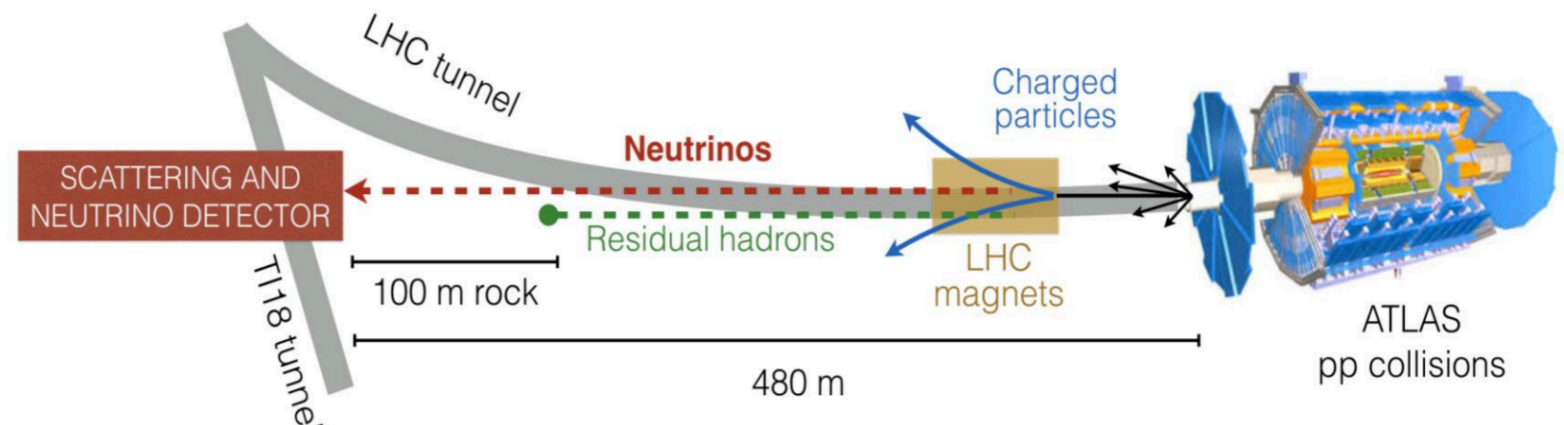
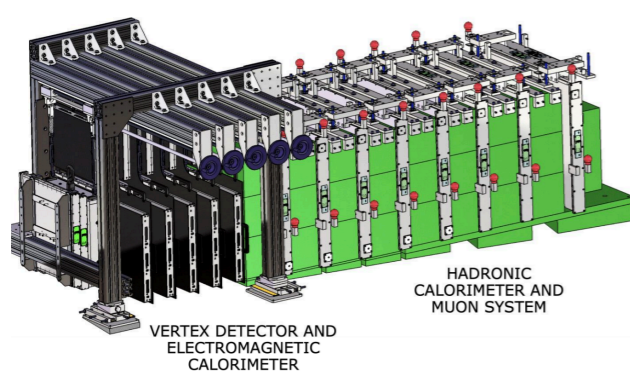
CEvNS proposal

coherent elastic neutrino nucleus scattering propto N^2

at the China Spallation Source CSNS

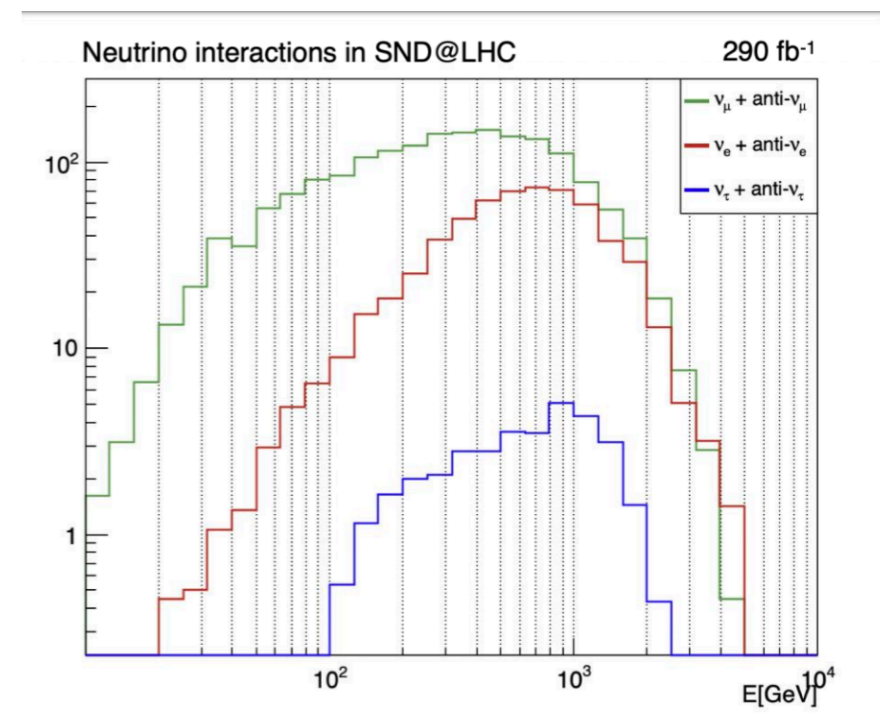
10.2 m from target, strong flux (10^{10} per cm^2h per flavour)





LHC provides high energy neutrino in all three types around E3 GeV

special consideration to the modelling started running - stay tuned!

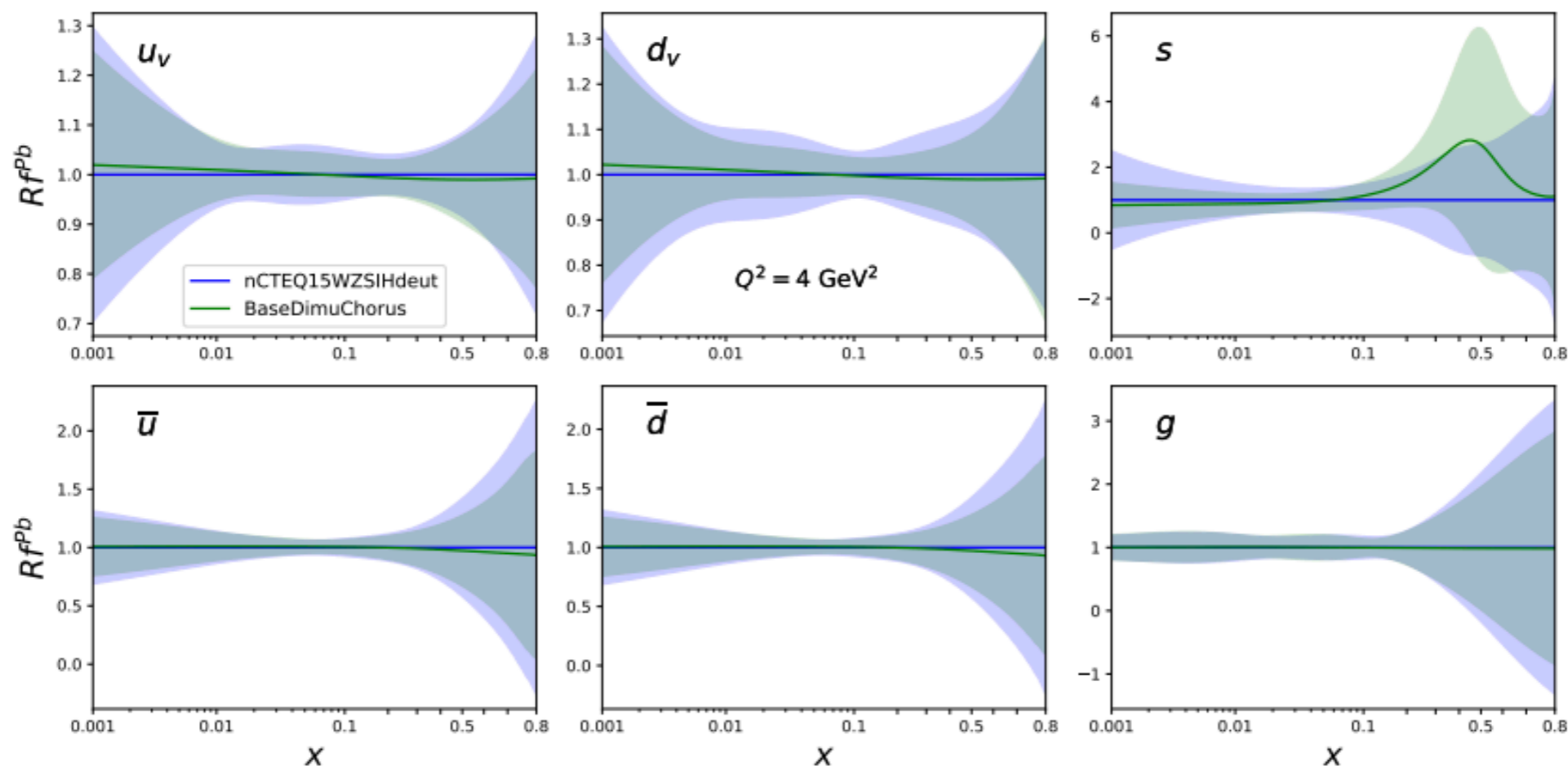


Giving Back

Nuclear PDFs with neutrino DIS data!

Richard Ruiz

Plotted: ratio of **BaseDimuChorus** PDF to **nCTEQ15WZSIHdeut** ν PB



Relatively nice agreement, tension found in similar analysis with Fe

Coherent elastic neutrino nucleus scattering

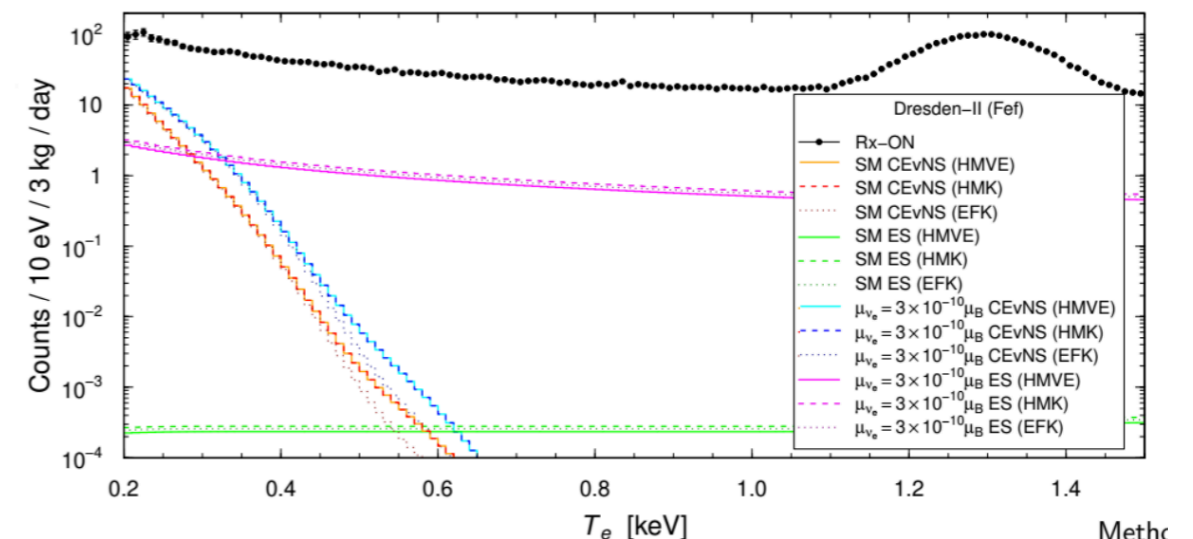
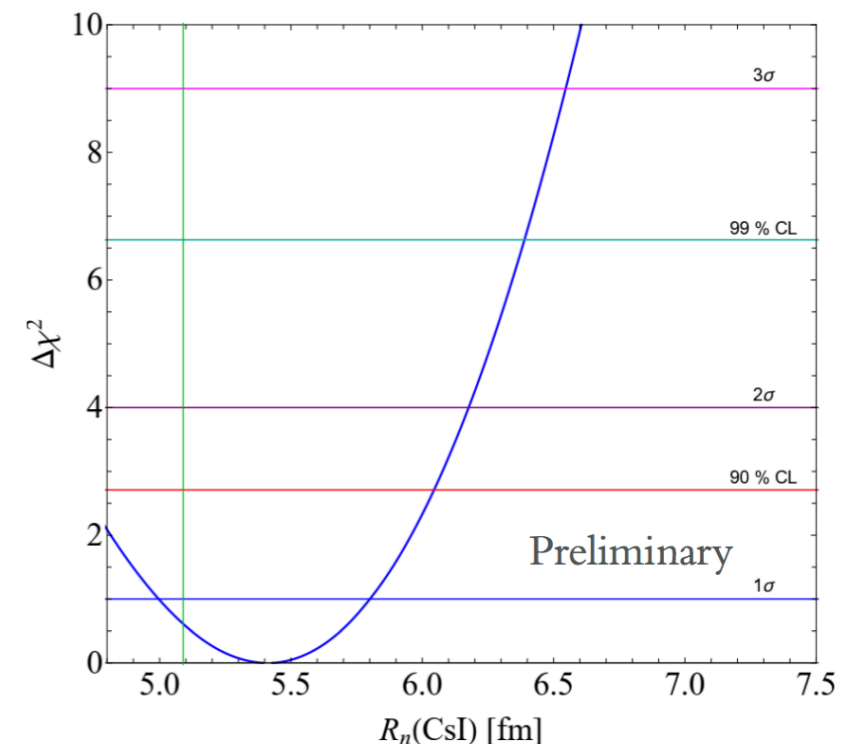
Matteo Cadeddu

Coherent experiment using Ar, CsI and now also Gr

Presenting an update to the neutron form factor and radius measurement $R_n^{\text{CsI}} = 5.4 \pm 0.4$ fm

Complimentary measurement of atomic parity violation in Cs

More input on the neutrino properties



$$|\mu_{\nu_e}| < 2.13 \times 10^{-10} \mu_B \quad \text{Dresden - II (CE}\nu\text{NS + ES),}$$

$$|\mu_{\nu_\mu}| < 18 \times 10^{-10} \mu_B \quad \text{CsI (CE}\nu\text{NS + ES) + Ar (CE}\nu\text{NS),}$$

Summary

The NuFACT community highly appreciate the need in better understanding of νA interaction

Tremendous effort on

- Improving theory
- Implementation in event generators
- Producing reliable cross section measurement and use external data to provide constraints

Looking forward to

many more results to come and to meet again

